Appendix L: Climate impacts and adaptation actions for shrub-steppe

The Washington-British Columbia Transboundary Climate-Connectivity Project engaged science-management partnerships to identify potential climate impacts on wildlife habitat connectivity and adaptation actions for addressing these impacts in the transboundary region of Washington and British Columbia.[i] Project partners focused their assessment on a suite of case study species, vegetation systems, and regions chosen for their shared priority status among project partners, representation of diverse habitat types and climate sensitivities, and data availability. This appendix describes potential climate impacts and adaptation actions identified for shrub-steppe vegetation communities.

Figure L.1. Shrub-steppe vegetation.

Shrub-steppe is the dominant vegetation type found in the Columbia Plateau ecoregion of the Pacific Northwest. Within the Washington-British Columbia transboundary region, shrub-steppe communities are highly fragmented due to agricultural, residential, and commercial development. Additional threats to shrub-steppe communities include changes in fire regime from wildfire suppression and invasive cheat grass (*Bromus tectorum*), intensive grazing pressure from cattle, and increasing energy extraction activities across the region.[2]

Future climate change may present additional challenges and needs for shrub-steppe habitat connectivity.[3-4] First, climate change may impact shrub-steppe core habitat areas and corridors in ways that may make them more or less permeable to wildlife movement. Second, existing shrub-steppe core habitat areas and corridors may be distributed on the landscape in ways that make them more or less able to accommodate climate-driven shifts in distributions of shrub-steppe species. For such reasons, connectivity enhancement has become the most frequently recommended climate adaptation strategy for biodiversity conservation.[5] However, little work has been done to translate this broad strategy into specific, on-the-ground actions. Furthermore, to our knowledge, no previous work has identified specific climate impacts or adaptation responses for shrub-steppe habitat connectivity (but see Michalak et al. 2014).[2] To address these needs, we describe here a novel effort to identify and address potential climate impacts on shrub-steppe habitat connectivity in the transboundary region of Washington and British Columbia.

Potential climate impacts on habitat connectivity

To identify potential climate impacts on transboundary shrub-steppe habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence shrub-steppe habitat connectivity, which of those are expected to be influenced by climate, and how (Appendix L.2). Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The shrub-

[i] This report is Appendix L of the Washington-British Columbia Transboundary Climate-Connectivity Project; for more information about the project's rationale, partners, methods, and results, see Krosby et al. (2016).[1]

steppe conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to shrub-steppe habitat connectivity.

Project participants used conceptual models in conjunction with maps of projected future changes in species distributions, vegetation communities, and relevant climate variables to identify potential impacts on shrub-steppe connectivity. Because a key project goal was to increase practitioner partners' capacity to access, interpret, and apply existing climate and connectivity models to their decision-making, we relied on a few primary datasets that are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[7,8] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[9] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] and models of projected range shifts produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[11]

Key impacts on transboundary shrub-steppe connectivity identified via this approach include changes in vegetation, changes in fire regime, changes in invasive species, and changes in land use.

Changes in vegetation

Climate change may impact shrub-steppe habitat connectivity by changing the extent and location of areas of climatic suitability for plant species associated with shrub-steppe communities; this may render some existing core habitat areas and corridors unsuitable for shrub-steppe species, and/or create new areas of suitability. Two types of models are available that estimate future changes in vegetation for the transboundary region: climatic niche models and mechanistic models.[ii]

Climatic niche models (CNM) are available for big sagebrush (*Artemisia tridentata*), a dominant shrub-steppe plant species. Projected changes for big sagebrush are available based on five climate models (BCCR BCM2.0, CCCMA CGCM3, CSIRO MK 3.0, INMCM 3.0, and MIROC3.2 MEDRES)[iii] for the 2080s under the A2 (high) carbon emissions scenario[iv] (Appendix L.3). Under all five climate models, the Okanagan Valley and the northern section of the Columbia Plateau are projected to remain climatically suitable for big sagebrush. In addition, for a majority of climate models, adjacent upland areas become more climatically suitable for big sagebrush (Appendix L.3).

[ii] Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes as well as projected climate changes and potential effects of carbon dioxide fertilization. However, mechanistic models only projected changes to very general vegetation types such as cold forest, shrub steppe, or grassland.

[iii] Global circulation models simulate the response of the global climate system to increasing greenhouse gas concentrations.

[iv] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

In addition to the big sagebrush CNM, there are CNM and mechanistic models that estimate future changes in vegetation types (rather than individual plant species) for the transboundary region. Both sets of models are based on results from two CMIP3 global circulation models (CGCM3.1(T47) and UKMO-HadCM3),[v] using the A2 (high) emissions scenario.[iv] While CNM vegetation models project stable or improving climatic conditions for sagebrush in and around the Okanagan Valley, mechanistic vegetation models project encroachment of "cool open forest woodland" vegetation into the Valley by the end of the century. Under the UKMO-HadCM3 scenario, this transformation is extensive and includes the lowlands adjacent to the Okanagan Valley itself. Under the CGCM3.1(T47) scenario, the lowland vegetation adjacent to the valley remains "cool forest," although much of the Okanagan Valley and northern Columbia Plateau transition to "cool open forest woodland."[vi]

Changes in disturbance regimes

Climate change may affect shrub-steppe habitat connectivity by increasing the frequency and severity of summer drought (Appendix L.4: Dry Spell Duration; Soil Moisture, July-September) and increasing the risk of wildfires (Appendix L.4: Days with High Fire Risk). While fire can help prevent tree encroachment into shrub-steppe communities, [13] an increase in fire frequency may prevent sagebrush seedlings from establishing, and fires that are too severe can scorch the soil and prevent regrowth of vegetation.[14] Impacts of increasing fire risk on shrub-steppe habitat connectivity will thus ultimately depend on fire return intervals, severity, and size, and on the subsequent successional trajectories of vegetation.

Changes in invasive species

Cheatgrass is an invasive species with devastating affects on shrub-steppe communities. Climate change could influence the distribution and invasiveness of cheatgrass due to its sensitivity to changes in temperature, precipitation, and fire regime.[2] Cheatgrass CNMs for the Columbia Plateau project either no change or a shrinking climatic niche space for cheatgrass,[15] which would have a positive affect on shrub-steppe habitat connectivity. However, CNMs do not account for the influence of fire on habitat suitability. Projected increases in fire risk (Appendix L.4: Days with High Fire Risk) may promote cheat grass invasion in shrub-steppe communities, negatively affecting habitat connectivity.

Changes in land use

Climate change may lead to changes in the location and productivity of agriculture. In particular, the Okanagan Valley and northern Columbia Plateau could become more productive for vineyards.[16] Vineyard acreage in the Okanagan has expanded in recent years[17] and changing climate conditions could make it profitable to expand vineyards into higher elevations. Warmer and drier conditions and reduced water availability from loss of snowpack (Appendix L.4: Spring (April 1st) Snowpack) could also increase the need for irrigation, placing additional stress on water resources. Such changes in land use would negatively affect shrub-steppe habitat connectivity.

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[v] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

[vi] The distinction between "cool forest" and "cool open forest woodland" is that the former forest type is >10 meters tall while the latter is < 10 meters tall.[12]

Adaptation responses

After identifying potential climate impacts on shrub-steppe connectivity, project participants used conceptual models to identify which relevant landscape features or processes could be affected by management activities, and subsequently what actions could be taken to address projected climate impacts (Appendix L.2). Key adaptation actions identified by this approach fall under three main categories: those that address potential climate impacts on shrub-steppe habitat connectivity, those that address novel habitat connectivity needs for promoting climate-induced shifts in shrub-steppe distributions, and those that identify spatial priorities for implementation.

Addressing climate impacts to shrub-steppe connectivity

Actions to address potential changes in vegetation type include:

- Developing a monitoring plan for shrub-steppe, particularly within key habitat areas and corridors, and areas of projected expansion. Because model projections show a fair amount of uncertainty regarding future changes in vegetation, monitoring changes will be critical for rapid detection and response to impacts on habitat connectivity.
- Forest encroachment could be limited, though likely just temporarily, by mechanically removing invading trees or using prescribed burns to reduce tree recruitment.
- Continuing best management practices for maintaining high quality shrub-steppe communities may increase the resilience of core habitat areas and corridors to future change.[vii]
- Facilitating migration of big sagebrush populations that are locally adapted to warmer climatic conditions may help to maintain shrub-steppe communities under future change.

Actions to address the potential for climate change to impact connectivity through more frequent and severe wildfires include:

- Using prescribed burns to reduce the risk of catastrophic wildfires that could negatively impact shrub-steppe core habitat areas and corridors. More frequent, smaller fires may create a patchy mosaic that can help prevent large, catastrophic fires.
- Referencing tribal practices to identify traditional strategies for managing fire risk and other potential climate impacts.
- In developed areas, implementing a new prescribed burn program would require careful evaluation of associated risks and benefits.
- Incorporating projections and observations of climatic changes (e.g., earlier onset of fire season) to inform the timing of fire prevention techniques as conditions change, in order to maximize safety and effectiveness.

Actions to address potential changes in invasive species include:

- In areas heavily invaded by cheatgrass, considering prescribed burning in combination with herbicide and native plant reseeding efforts.[19]
- Incorporate invasive species management into all activities related to habitat connectivity conservation.

[vii] For example, see management recommendations from Altman and Holmes (2000).[18]

Actions to address potential changes in land use include:

- Managing access in shrub-steppe core habitat areas and corridors to reduce impacts from recreation, grazing, and other uses.

Enhancing connectivity to facilitate range shifts

Actions that may help shrub-steppe species adjust their ranges to track shifts in their areas of climatic suitability include:

- Maintaining and restoring corridors that span elevation gradients (e.g., climate-gradient corridors,[8] Appendix L.1), to facilitate the dispersal of shrub-steppe species into cooler, higher elevation habitats as the climate warms. Climate-gradient corridors may be particularly important for small animals and plants, such as big sagebrush, that have limited mobility, as these species may need to reside in corridors rather than simply move through them.
- Maintaining and restoring corridors between areas of declining climatic suitability and areas of stable or increasing suitability (Appendix L.3).

Spatial priorities for implementation

Spatial priorities for implementation of the adaptation actions described above include:

- Landscape integrity and climate-gradient corridors (Appendix L.1). Linkages that are in good natural condition (i.e., landscape integrity corridors[7]) and that span climate gradients (i.e., climate-gradient corridors[8]) may help promote dispersal of shrub-steppe plant species among existing habitat areas and into newly suitable habitat as the climate warms.
- Connectivity priority areas identified for the Okanagan-Kettle region (Appendix L.1).[20]

Policy considerations

Referrals response

Actions for addressing climate impacts on shrub-steppe connectivity through First Nations and tribal referrals processes include:

- Consider potential impacts on habitat connectivity during the referrals process, particularly for activities that may impact habitat connectivity needs (e.g., climate gradient corridors) under climate change.
- Look for opportunities to reduce grazing pressure in key corridors.

Land and water use planning and zoning

Actions for addressing climate impacts on shrub-steppe connectivity through land and water use planning and zoning include:

- Carefully reviewing permit requests for new irrigation withdrawals within core habitat areas and corridors, to ensure that water resources remain available for shrub-steppe species if summers become hotter and drier.
- Monitoring trends and reviewing policies relating to vineyard establishment. Strive to avoid establishing vineyards in shrub-steppe core habitat areas or corridors.
- Using large parcel zoning to maintain contiguity of natural areas within First Nation and tribal lands. Outside of these lands, work with private landowners and with environmental policy to maintain contiguous swaths of suitable land that will facilitate movement.

- Considering the establishment of additional conservation areas at elevations above the current shrub-steppe system, in order to accommodate upward range expansions of shrub-steppe species.
- Increasing the number of shrub-steppe protected areas, which could increase the resilience and permeability of the overall conservation network.
- Considering the full range of land protection and management approaches for habitat connectivity conservation, from land purchases and easements to stewardship activities.
- Coordinating stewardship and management activities with provincial and local governments, NGOs, First Nations and tribes, and especially with private landowners.
- Incorporating these adaptation actions into the management of conservation areas, working with a range of government, NGO, First Nation, tribal, and private landowner partners to anticipate and respond to climate impacts on shrub-steppe habitat connectivity.

Research needs

Future research that could help inform shrub-steppe connectivity conservation under climate change includes:

- Developing climatic niche models for additional shrub-steppe plant species. This would allow more thorough understanding of potential impacts on shrub-steppe habitat connectivity.
- Developing habitat connectivity models that incorporate projected changes in development within shrub-steppe habitats, including human response to climate change. This would improve the ability to anticipate future threats to shrub-steppe habitat connectivity.
- Evaluating the extent to which soil conditions and other ecological factors could support shrub-steppe vegetation in areas projected to become climatically suitable, to better anticipate and plan for future areas of expansion.
- Identifying climate resilient shrub-steppe core habitat areas and corridors. Overlay available corridor networks (Appendix L.1)[7] with projected changes in vegetation (Appendix L.3, Appendix L.4) and climate variables (Appendix L.5). Core areas and corridors that are projected by multiple models to retain suitable climatic conditions and vegetation, and to see the least change in relevant climatic variables, may be most likely to continue supporting shrub-steppe habitat and connectivity in the future. These climate-resilient habitat areas may be used as priority areas for the adaptation actions described above.

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Glossary of Terms

Assisted migration – Species and populations are deliberately planted or transported to new suitable habitat locations, typically in response to declines in historic habitat quality resulting from rapid environmental change, principally climate change.

Centrality — Refers to a group of landscape metrics that rank the importance of habitat patches or linkages in providing movement across an entire network, i.e., as "gatekeepers" of flow across a landscape.[viii]

Connectivity — Most commonly defined as the degree to which the landscape facilitates or impedes movement among resource patches.[ix] Can be important for maintaining ecological, population-level, or evolutionary processes.

Core Areas — Large blocks (10,000+ acres) of contiguous lands with relatively high landscape permeability.

Corridor — Refers to modeled movement routes or physical linear features on the landscape (e.g., continuous strips of riparian vegetation or transportation routes). In this document, the term "corridor" is most often used in the context of modeled least-cost corridors, i.e., the most efficient movement pathways for wildlife and ecological processes that connect HCAs or core areas. These are areas predicted to be important for migration, dispersal, or gene flow, or for shifting ranges in response to climate change and other factors affecting the distribution of habitat.

Desiccation – Extreme water deprivation, or process of extreme drying.

Dispersal — Relatively permanent movement of an individual from an area, such as movement of a juvenile away from its place of birth.

Fracture Zone — An area of reduced permeability between core areas. Most fracture zones need significant restoration to function as reliable linkages. Portions of a fracture zone may be potential linkage zones.

Habitat Connectivity — See Connectivity.

Landscape Connectivity — See Connectivity.

Permeability — The ability of a landscape to support movement of plants, animals, or processes.

[viii] Carroll, C. 2010. Connectivity analysis toolkit user manual. Version 1.1. Klamath Center for Conservation Research, Orleans, California. Available at www.connectivitytools.org (accessed January 2016).

[ix] Taylor, P. D., L. Fahrig, K. Henein, and G. Merriam. 1993. Connectivity is a vital element of landscape structure. *Oikos* 68: 571-573.

Pinch point — Portion of the landscape where movement is funneled through a narrow area. Pinch points can make linkages vulnerable to further habitat loss because the loss of a small area can sever the linkage entirely. Synonyms are bottleneck and choke point.

Refugia – Geographical areas where a population can survive through periods of unfavorable environmental conditions (e.g., climate-related effects).

Thermal barriers – Water temperatures warm enough to prevent migration of a given fish species. These barriers can prevent or delay spawning for migrating salmonids.

Appendices L.1-5

Appendices include all materials used to identify potential climate impacts on habitat connectivity for case study species, vegetation systems, and regions. For shrub-steppe, these materials include:

Appendix L.1. Habitat connectivity models
Appendix L.2. Conceptual model of habitat connectivity
Appendix L.3. Climatic niche models
Appendix L.4. Projected changes in vegetation communities
Appendix L.5. Projected changes in relevant climatic variables

All maps included in these appendices are derived from a few primary datasets, chosen because they are freely available, span all or part of the transboundary region, and reflect the expertise of project science partners. These sources include habitat connectivity models produced by the Washington Connected Landscapes Project,[7,8] future climate projections from the Integrated Scenarios of the Pacific Northwest Environment[9] and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] and models of projected range shifts and vegetation change produced as part of the Pacific Northwest Climate Change Vulnerability Assessment.[11]

All maps are provided at three geographic extents corresponding to the distinct geographies of the three project partnerships (Fig. L.2):

i. **Okanagan Nation Territory**, the assessment area for project partners: Okanagan Nation Alliance and its member bands and tribes, including Colville Confederated Tribes.
ii. **The Okanagan-Kettle Region**, the assessment area for project partners: Transboundary Connectivity Working Group (i.e., the Washington Habitat Connectivity Working Group and its BC partners).
iii. **The Washington-British Columbia Transboundary Region**, the assessment area for project partners: BC Parks; BC Forests, Lands, and Natural Resource Operations; US Forest Service; and US National Park Service.

All project reports, data layers, and associated metadata are freely available online at:
https://nplcc.databasin.org/galleries/5a3a424b36ba4b63b10b8170ea0c915e

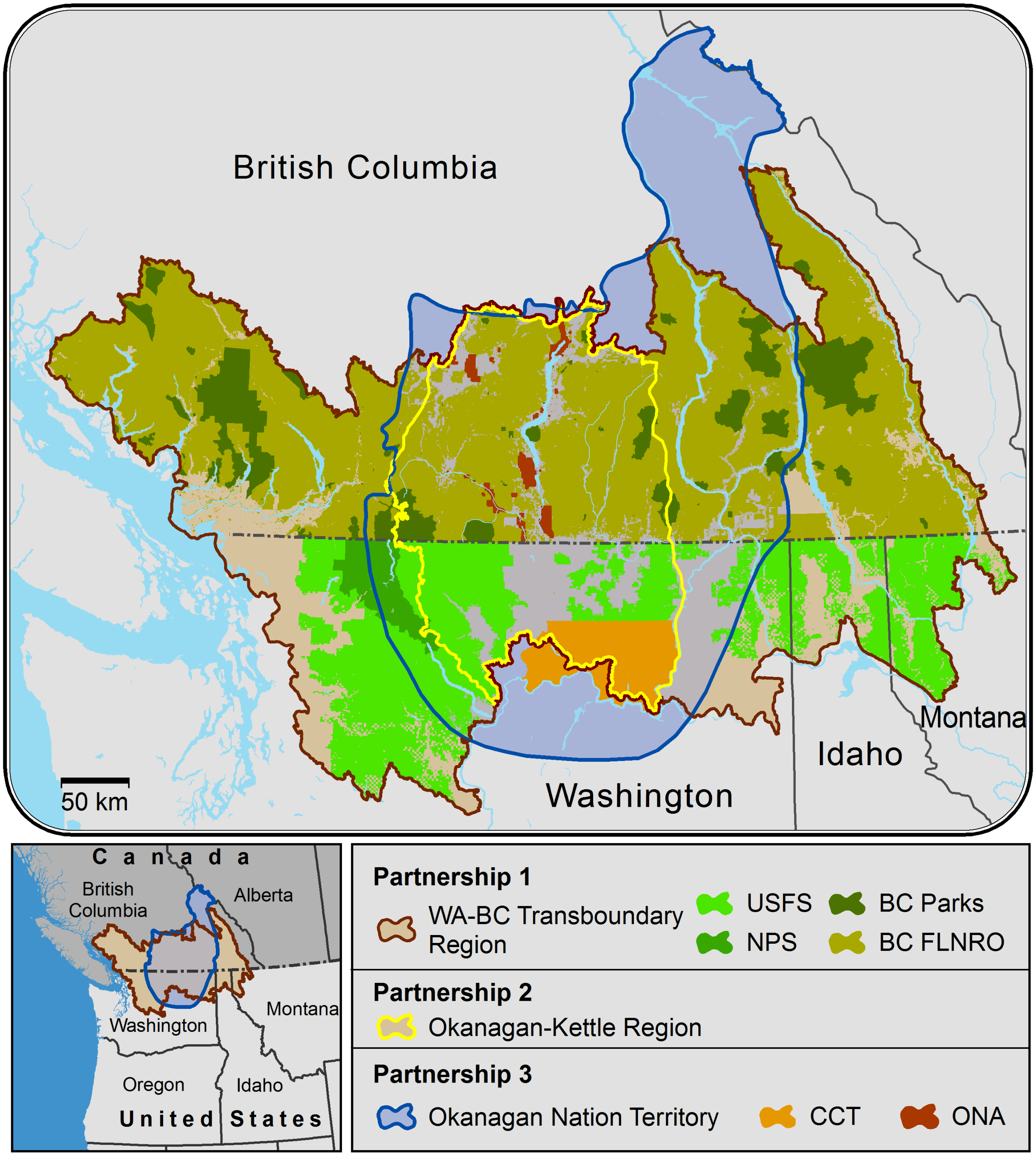

Figure L.2. Project partners and assessment areas.

Appendix L.1. Habitat Connectivity Models

Habitat connectivity models are available from the Washington Connected Landscapes Project.[x] These models can be used to prioritize areas for maintaining and restoring habitat connectivity now and in the future as the climate changes. Available models include species corridor networks, landscape integrity corridor networks, and climate-gradient corridor networks. These models are available at two distinct scales (though for many species, only one scale is available or was selected for use by project participants): 1) **WHCWG Statewide** models span Washington State and surrounding areas of Oregon, Idaho, and British Columbia; 2) **WHCWG Columbia Plateau** models span the Columbia Plateau ecoregion within Washington State, and do not extend into British Columbia; 3) **Transboundary Working Group Okanagan-Kettle** models span the Okanagan-Kettle region.

a) **WHCWG Statewide Analysis: Landscape Integrity Corridor Network.**[7] This map shows corridor networks connecting core habitat areas (green polygons) for areas of high landscape integrity (e.g., areas with few roads, agricultural areas, or urban areas). Corridors are represented as yellow areas, with resistance to movement increasing as yellow transitions to blue. Green areas represent large, contiguous core areas of high landscape integrity. The northern extent of this analysis falls just north of Kamloops, BC.

b) **WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity).**[8] This map shows corridors (glowing white areas, with resistance to movement increasing as white fades to black) connecting core habitat areas (polygons, shaded to reflect mean annual temperatures) that are of high landscape integrity (i.e., have low levels of human modification) and differ in temperature by >1 ^{o}C. These corridors thus allow for movement between relatively warmer and cooler core habitat areas, while avoiding areas of low landscape integrity (e.g., roads, agricultural areas, urban areas), and minimizing major changes in temperature along the way (e.g., crossing over cold peaks or dipping into warm valleys). The northern extent of this analysis falls just north of Kamloops, BC.

c) **Okanagan-Kettle Connectivity Assessment: Connectivity Focus Areas.**[20] This map shows connectivity focus areas (CFAs) identified for the Okanagan-Kettle region. CFAs (in purple) used connectivity value and development risk models to identify those places within the Okanagan-Kettle region where wildlife would likely move when migrating or making dispersal movements and that are also the most threatened by potential development. This map shows a composite of CFAs for shrub-steppe species, montane species, and landscape integrity models; CFAs move from pink to purple with increasing number of overlapping models.

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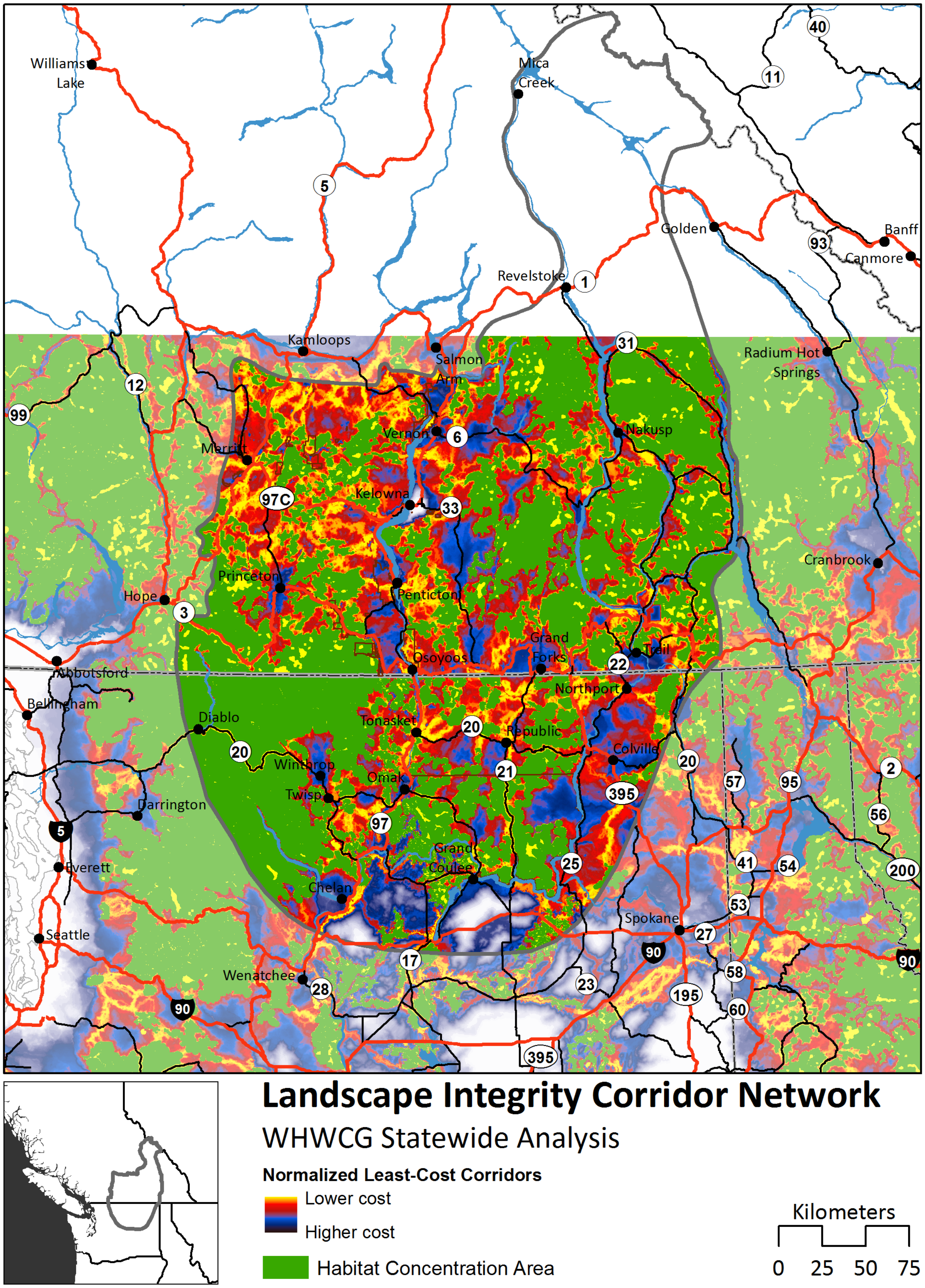
[x] For detailed methodology and data layers see http://www.waconnected.org.

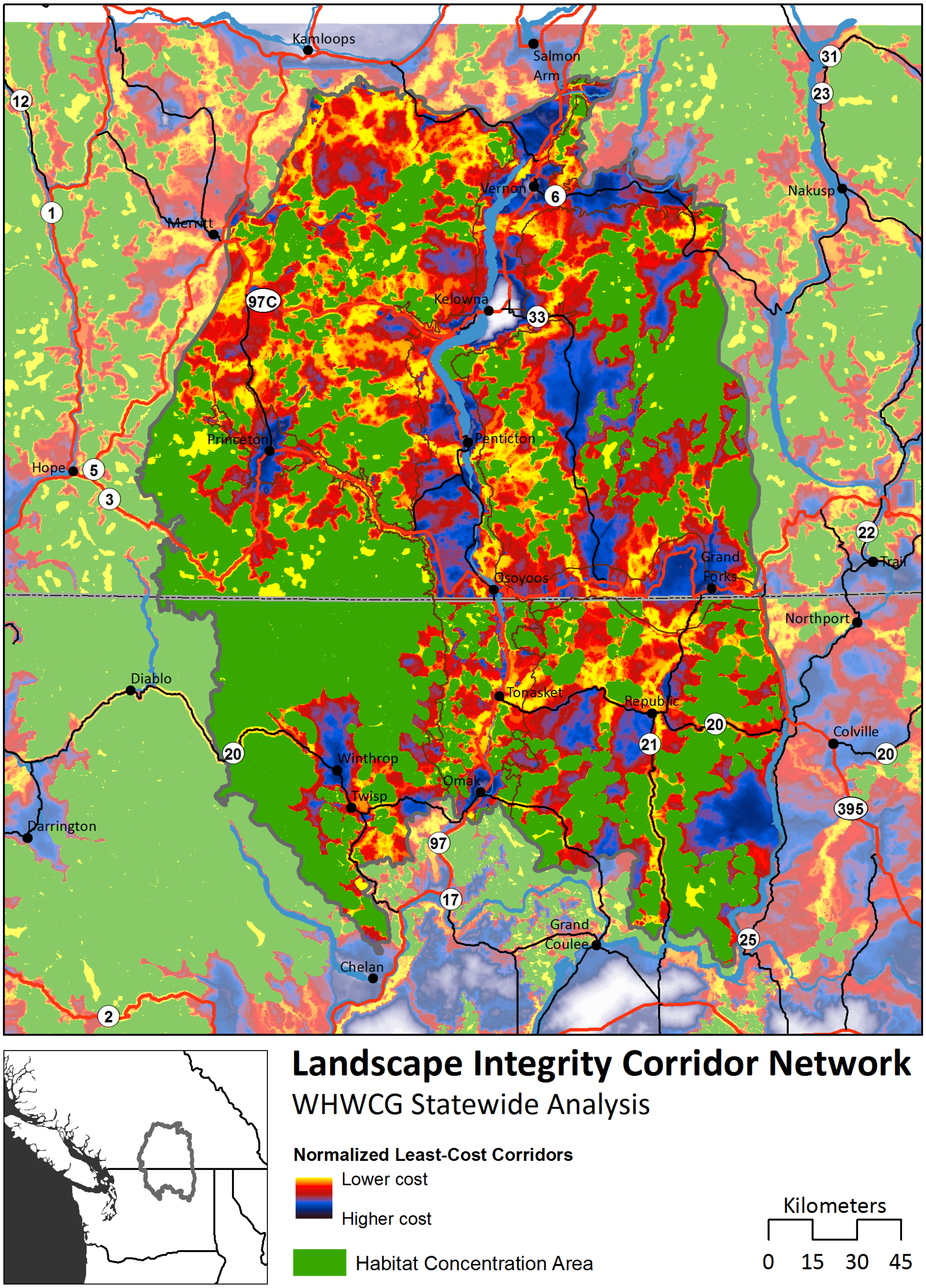
Appendix L.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

i) Extent: Okanagan Nation Territory



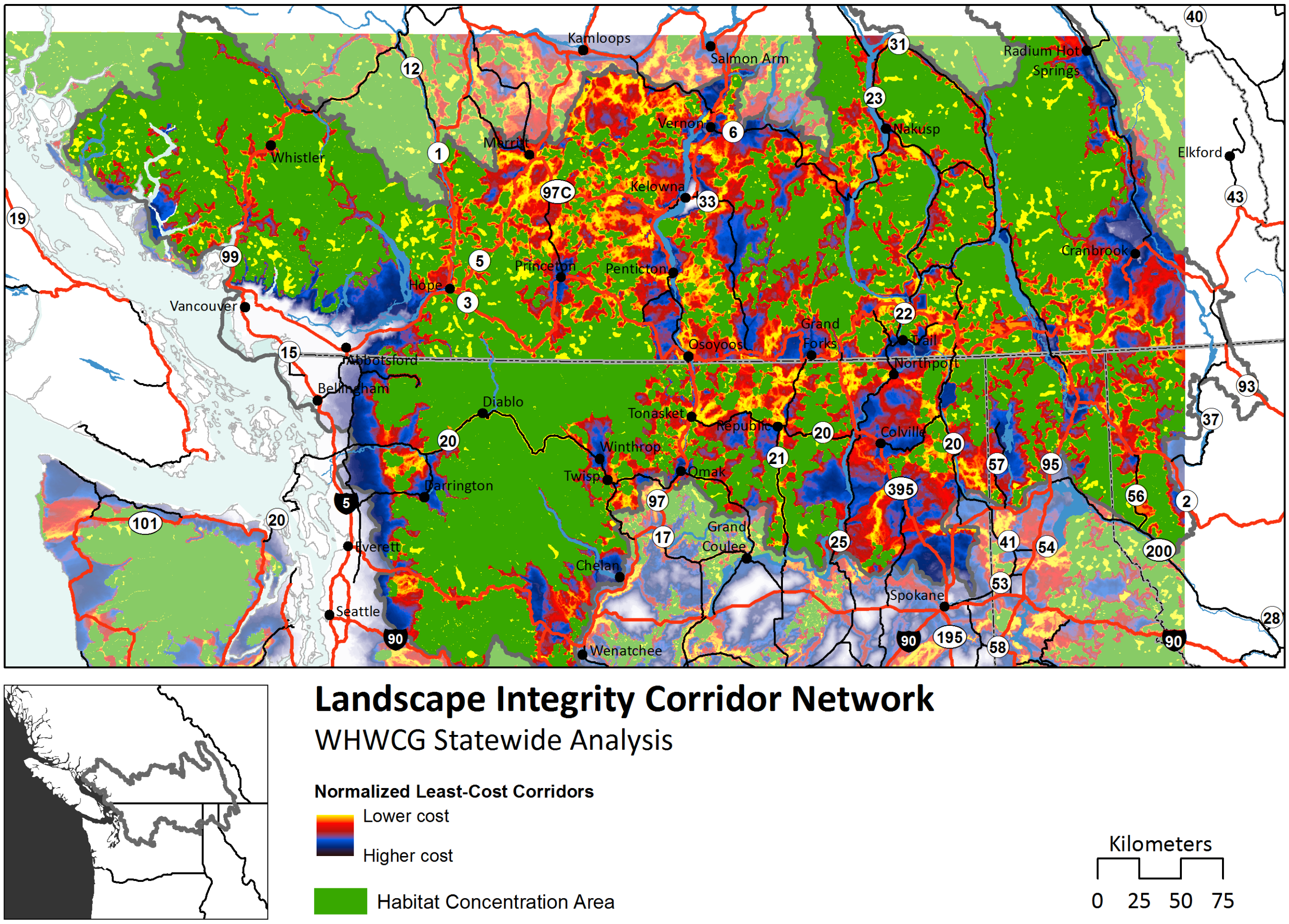
Appendix L.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

ii) Extent: Okanagan-Kettle Region



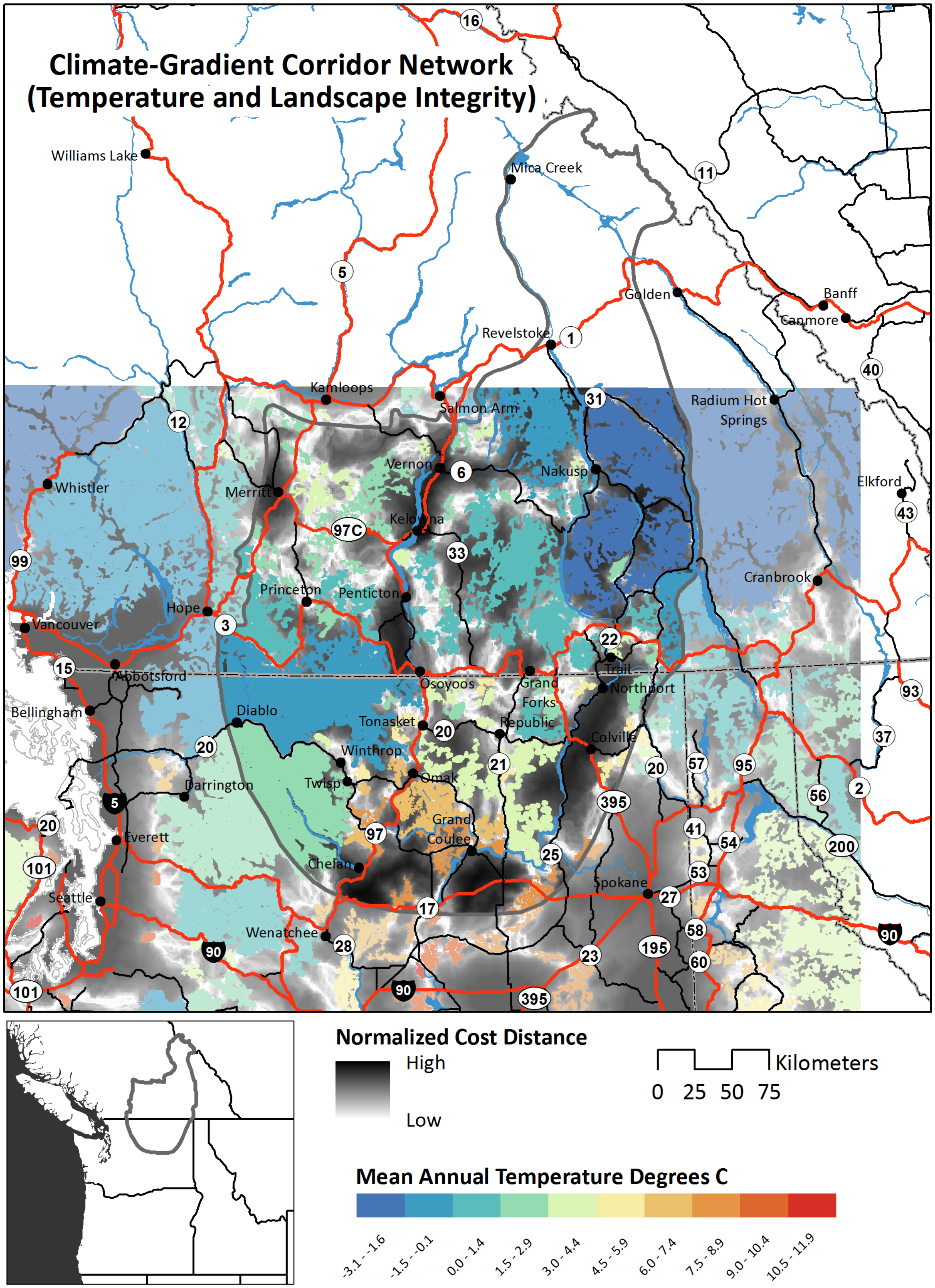
Appendix L.1a. WHCWG Statewide Analysis: Landscape Integrity Corridor Network

iii) Extent: Washington-British Columbia Transboundary Region



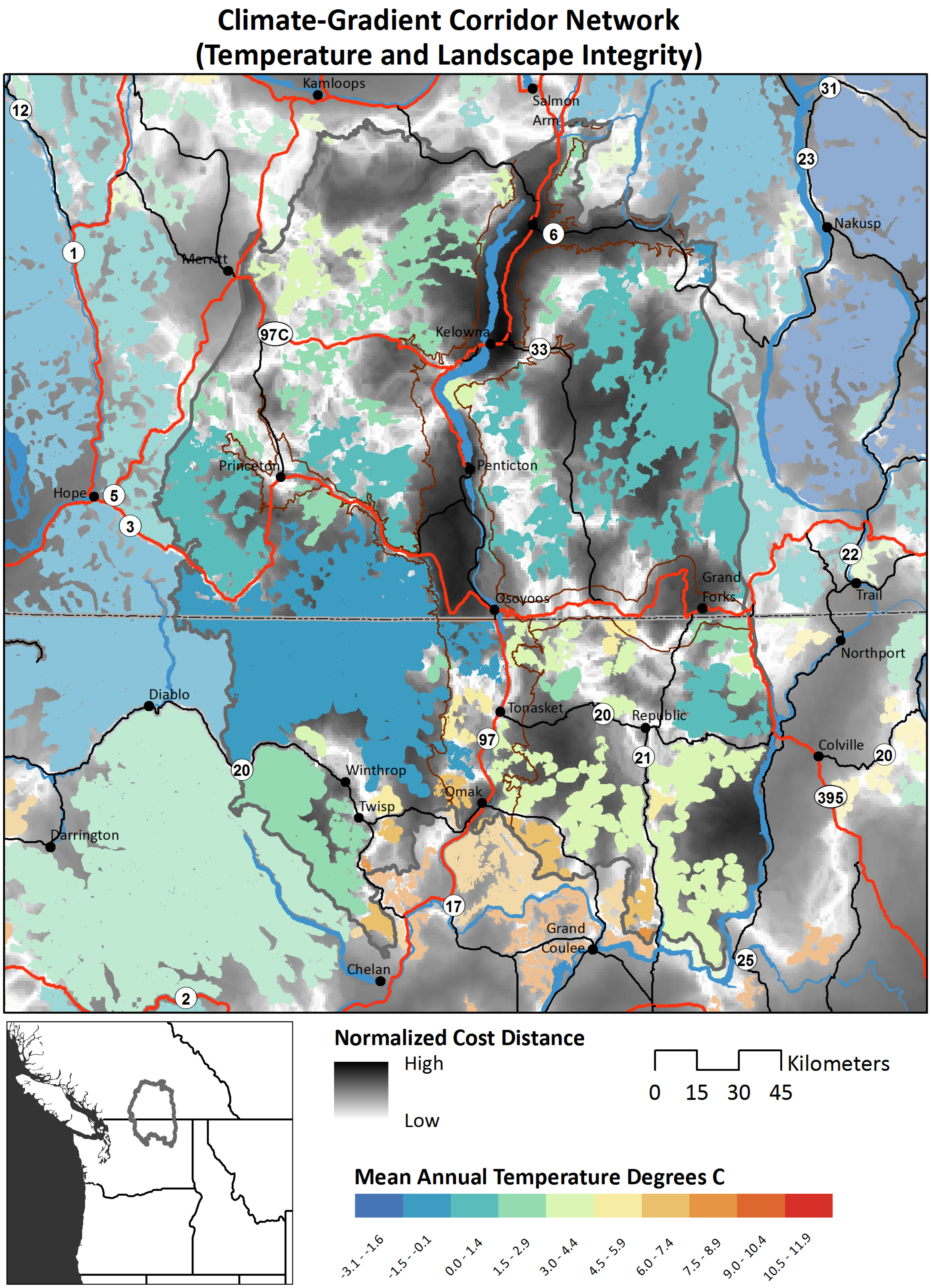
Appendix L.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

i) Extent: Okanagan Nation Territory



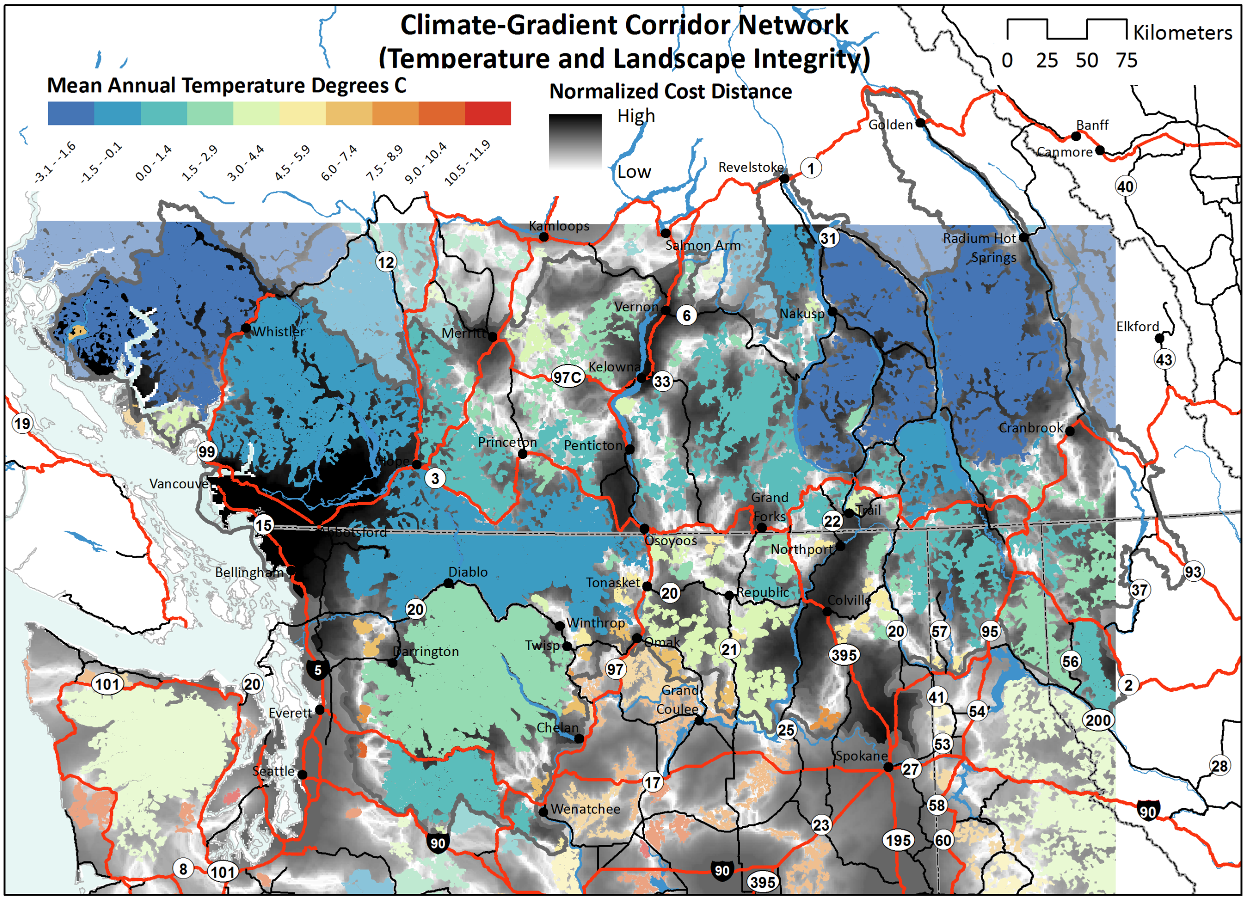
Appendix L.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

ii) Extent: Okanagan-Kettle Region



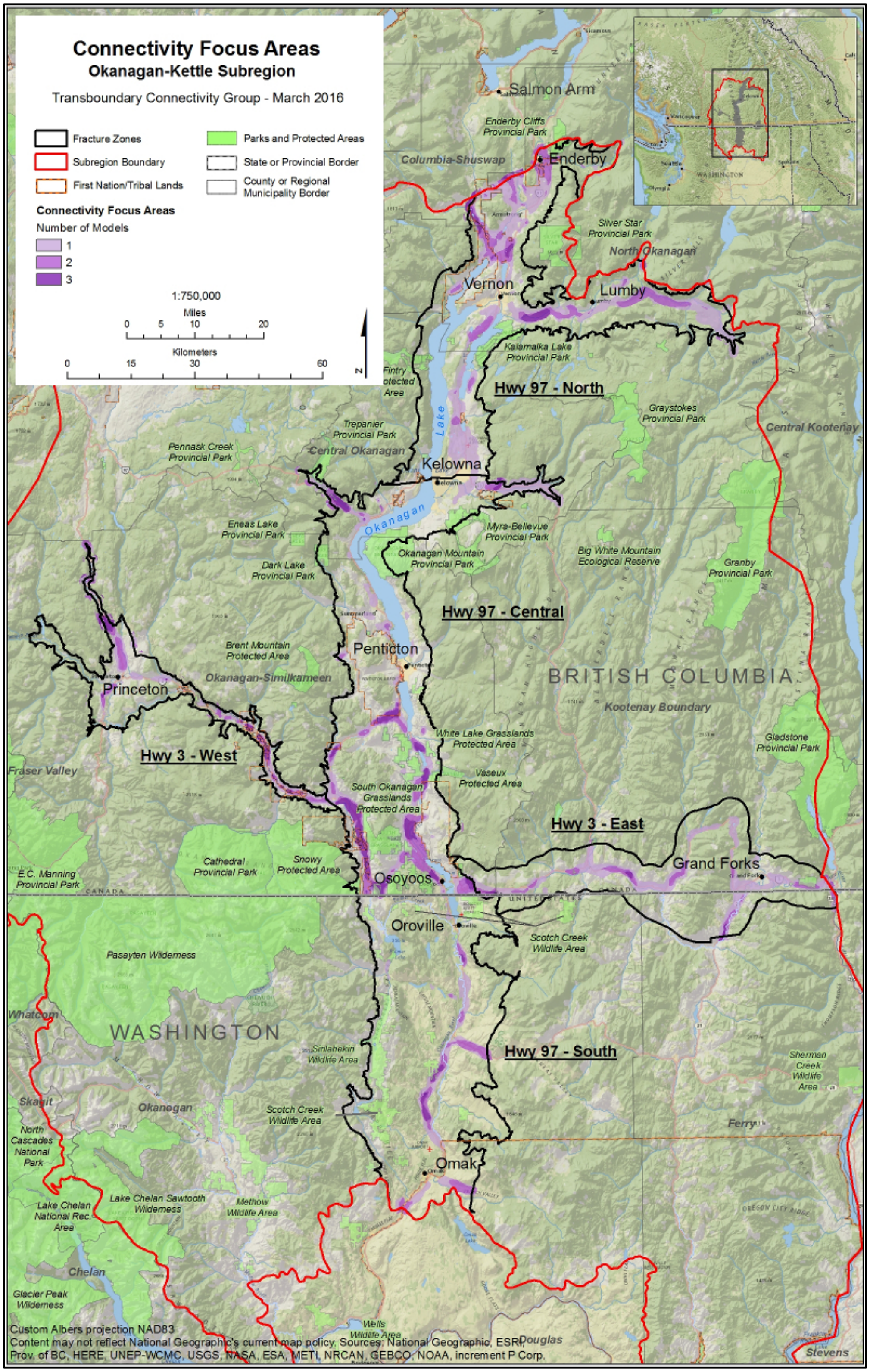
Appendix L.1b. WHCWG Statewide Analysis: Climate-Gradient Corridor Network (Temperature + Landscape Integrity)

iii) Extent: Washington-British Columbia Transboundary Region



Appendix L.1c. Okanagan-Kettle Connectivity Assessment: Connectivity Focus Areas

Extent: Okanagan-Kettle Region



Appendix L.2. Conceptual Model of Habitat Connectivity

To identify potential climate impacts on transboundary shrub-steppe habitat connectivity, project partners created a conceptual model that identifies the key landscape features and processes expected to influence shrub-steppe habitat connectivity, which of those are expected to be influenced by climate, and how. Simplifying complex ecological systems in such a way can make it easier to identify specific climate impacts and adaptation actions. For this reason, conceptual models have been promoted as useful adaptation tools, and have been applied in a variety of other systems.[6] The shrub-steppe conceptual model was developed using peer-reviewed articles and reports, project participant expertise, and review by species experts. That said, the resulting model is intentionally simplified, and should not be interpreted to represent a comprehensive assessment of the full suite of landscape features and processes contributing to Shrub-steppe habitat connectivity.

Conceptual models illustrate the relationships between the key landscape features (white boxes), ecological processes (rounded corner purple boxes), and human activities (rounded corner blue boxes) that influence the quality and permeability of core habitat and dispersal habitat for a given species. Climatic variables for which data on projected changes are available are highlighted with a yellow outline. Green arrows indicate a positive correlation between linked variables (i.e., as variable x increases variable y increases); note that a positive correlation is not necessarily beneficial to the species. Red arrows indicate a negative relationship between variables (i.e., as variable x increases, variable y decreases); again, negative correlations are not necessarily harmful to the species.

Expert reviewers for the shrub-steppe conceptual model included:

- Alison Peatt, RPBio, Environmental planner for South Okanagan-Similkameen communities
- Kirk Safford, BC Ministry of Environment
- Carmen Cadrin, British Columbia Conservation Data Centre.

Key references used to create the shrub-steppe conceptual model included:

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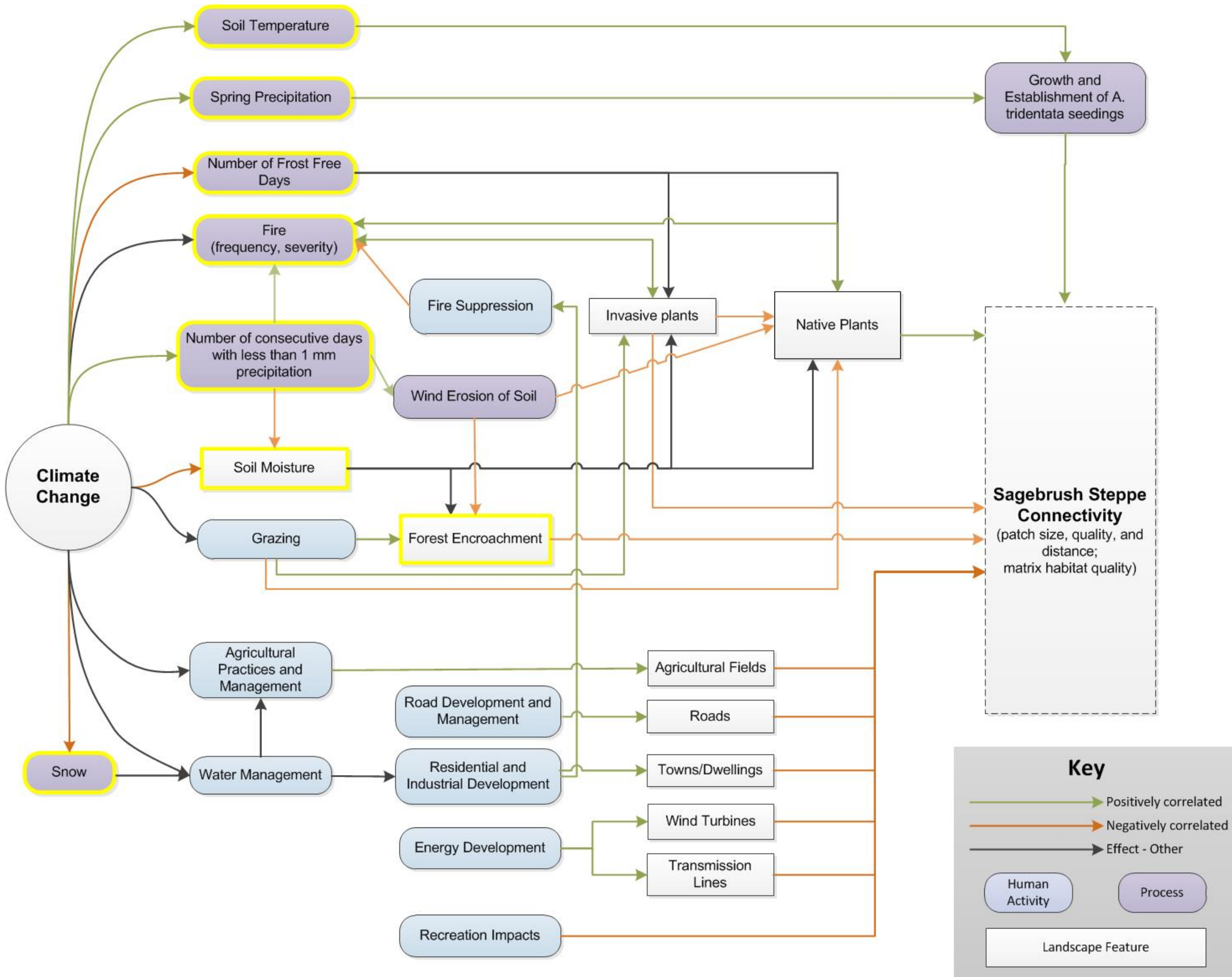
Appendix L.2. Conceptual Model of Shrub-Steppe Connectivity



Appendix L.3. Climatic Niche Models

Climatic niche models (CNM) mathematically define the climatic conditions within each species' current geographic distribution, and then apply projected climate changes to identify where on the landscape those climate conditions are projected to be located in the future. These maps show CNM results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[xi] Both models use the A2 (high) emissions scenario.[xii] CNMs are based on climate conditions alone and do not account for dispersal ability, genetic adaptation, interspecies interactions, or other aspects of habitat suitability. Once projected range shifts were modeled, current land uses and projected vegetation types (identified using Shafer et al. 2015[xiii]) that are unlikely to support species occurrence were removed. For example, areas currently defined as urban were removed for species unable to live in urban landscapes, and grassland habitats were removed for forest-dependent species. Both would be shown as unsuitable.

Dark gray areas indicate areas of the species' current range that are projected to remain climatically suitable by both GCMs (i.e., range is expected to remain "stable"). Dark pink areas are projected to become less climatically suitable by both GCMs (i.e., range is expected to "contract"). Light pink areas are projected to become less suitable under one model but remain stable under the other. Dark green areas are areas that are not within the species' current range but are projected to become climatically suitable by both GCMs (i.e., the range is expected to "expand"). Light green areas are projected to become climatically suitable by one GCM, but not the other.

[xi] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

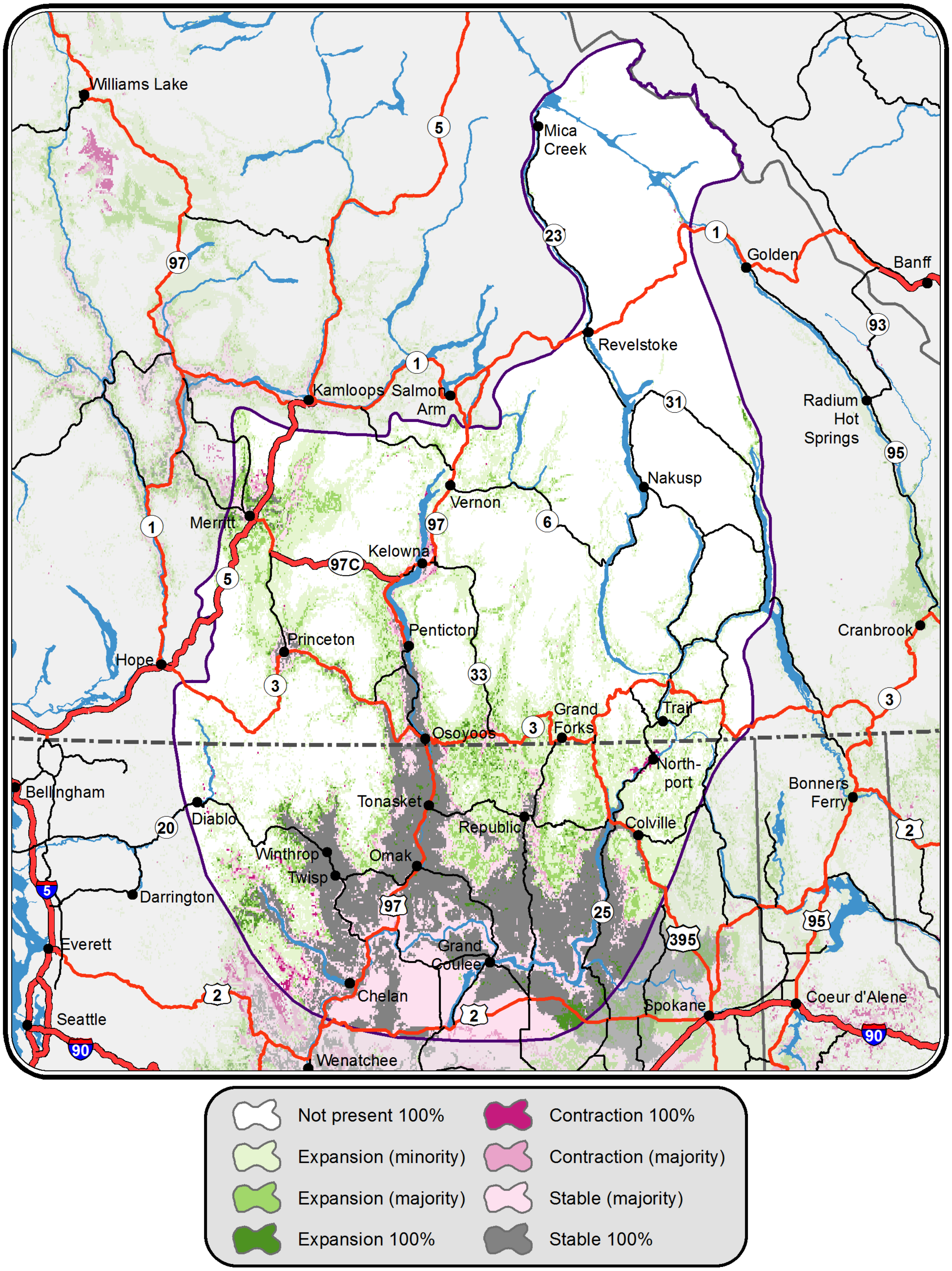
[xii] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[xiii] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the northwest United States and southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759

Appendix L.3. Shrub-Steppe Climatic Niche Model

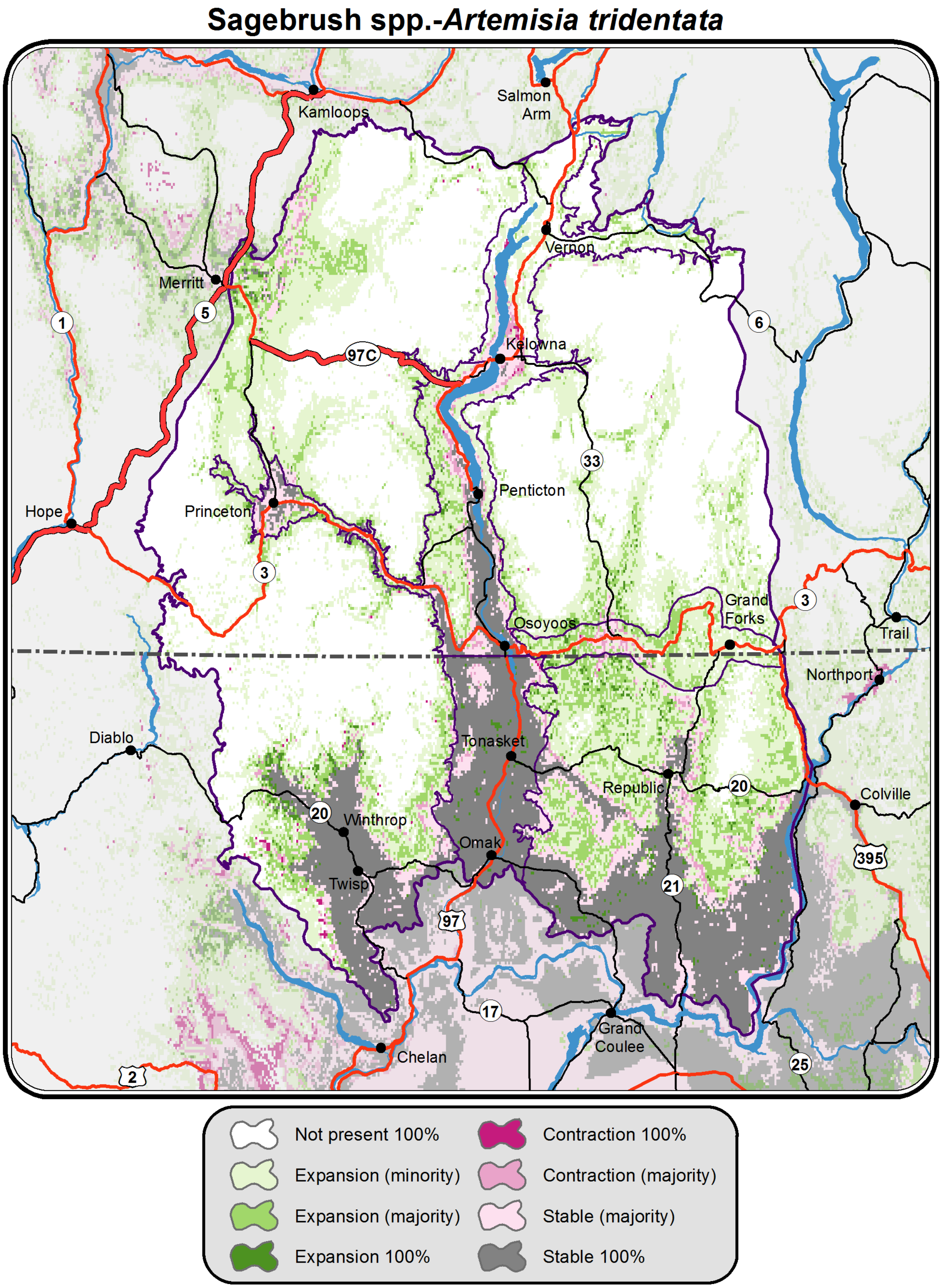
i) Extent: Okanagan Nation Territory

Sagebrush spp.-*Artemisia tridentata*



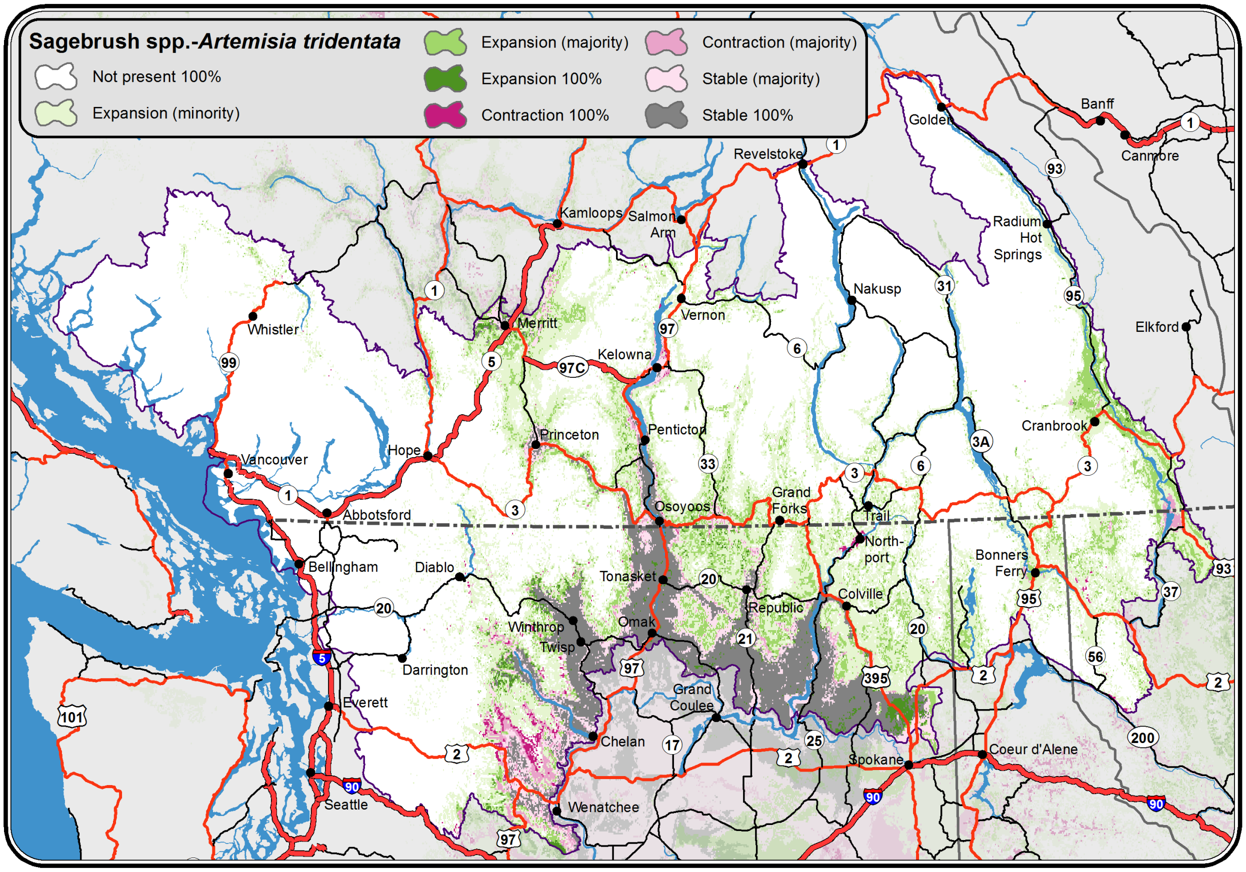
Appendix L.3. Shrub-Steppe Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



Appendix L.3. Shrub-Steppe Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix L.4. Projected Changes in Vegetation

Two types of models are available that project future changes in vegetation that could affect a species' habitat connectivity: climatic niche models and mechanistic models. Climatic niche vegetation models mathematically define the climatic conditions within a given vegetation type's current distribution and then project where on the landscape those conditions are expected to occur in the future. These models do not incorporate other important factors that determine vegetation such as soil suitability, dispersal, competition, and fire. In contrast, mechanistic vegetation models do incorporate these ecological processes, as well as projected climate changes and the potential effects of carbon dioxide fertilization. However, mechanistic models only project changes to very general vegetation types (e.g., cold forest, shrub steppe, or grassland). Both types of models included below show vegetation model results based on results from two CMIP3 Global Circulation Models (GCMs): CGCM3.1(T47) and UKMO-HadCM3.[xiv] Both models also use the A2 (high) emissions scenario.[xv]

a) **Biome Climatic Niche Vegetation Model.**[xvi] This climatic niche vegetation model shows the projected response of biomes or forest types to projected climate change.

b) **Mechanistic Vegetation Model.**[xvii] This mechanistic vegetation model shows simulated vegetation composition and distribution patterns under climate change.

[xiv] CGCM3.1(T47) and UKMO-HadCM3 are two Global Circulation Models (GCMs) which each project different potential future climate scenarios. The UKMO-HadCM3 model projects a much hotter and drier summer, while the CGCM3.1(T47) projects greater precipitation increases in spring, summer and fall. For these reasons, the UKMO-HadCM3 could be considered a "hot-dry" future, while the CGCM3.1(T47) could be considered a "warm-wet" future within the Pacific Northwest.

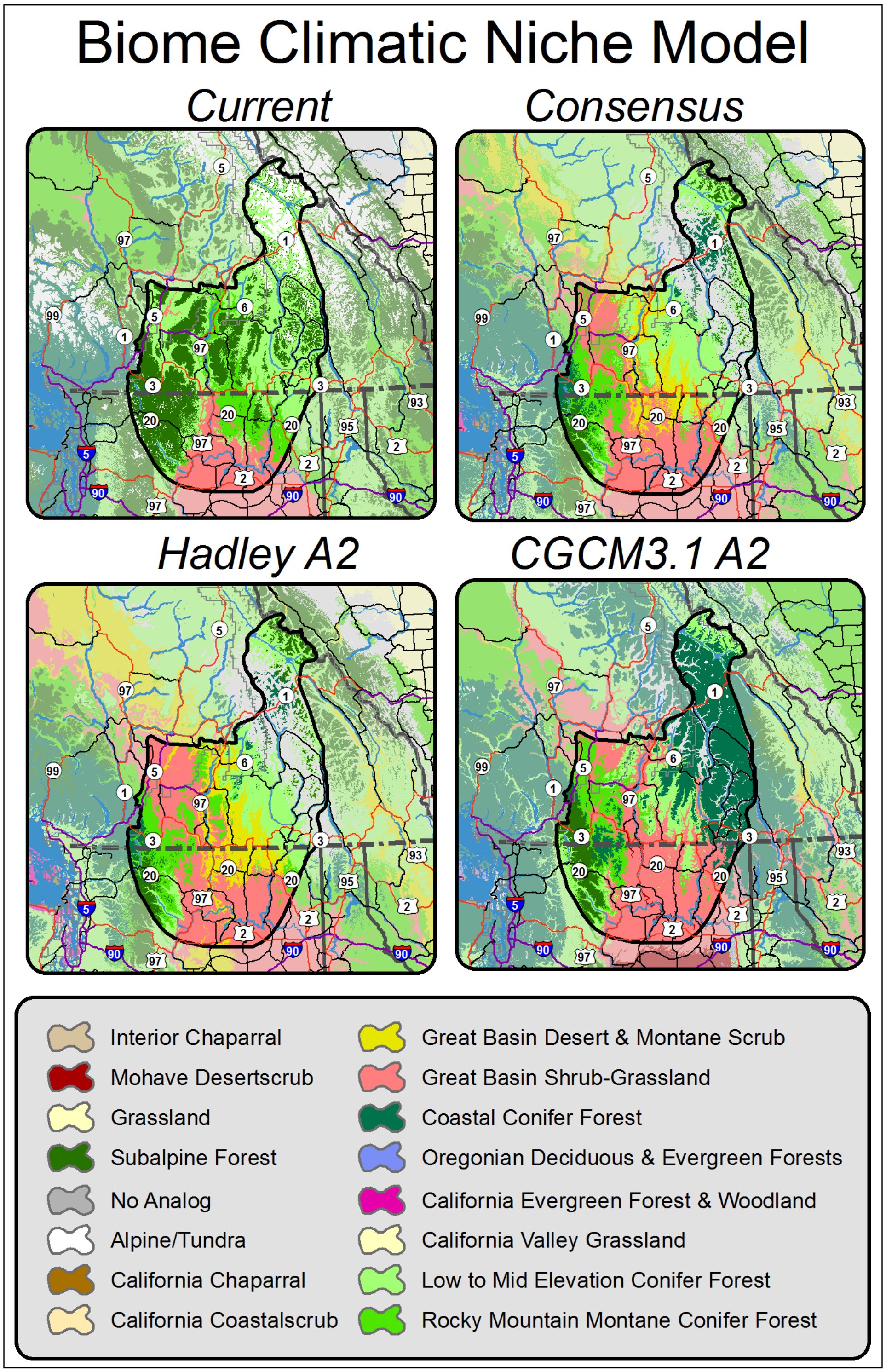
[xv] Emissions scenarios were developed by climate modeling centers for use in modeling global and regional climate-related effects. A2 is a high, "business as usual" scenario in which emissions of greenhouse gases continue to rise until the end of the 21st century, and atmospheric CO_2 concentrations more than triple by 2100 relative to pre-industrial levels.

[xvi] Rehfeldt, G.E., Crookston, N.L., Sánez-Romero, C., Campbell, E.M. 2012. North American vegetation model for land-use planning in a changing climate: a solution to large classification problems. *Ecological Applications* 22: 119-141.

[xvii] Shafer, S.L., Bartlein, P.J , Gray, E.M., and R.T. Pelltier. 2015. Projected future vegetation changes for the Northwest United States and Southwest Canada at a fine spatial resolution using a dynamic global vegetation model. *PLoS ONE* 10: e0138759. doi:10.1371/journal.pone.0138759.

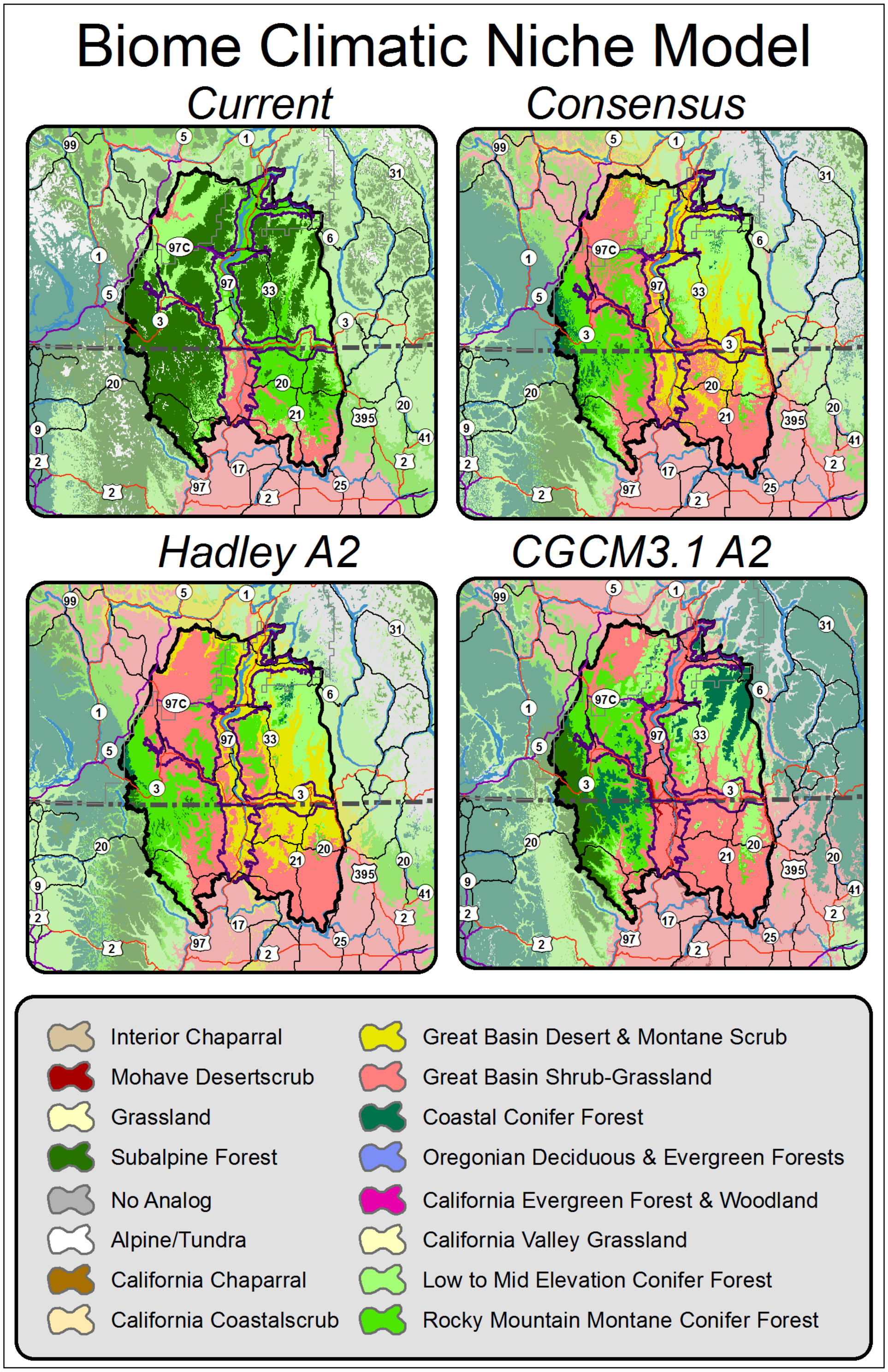
Appendix L.4a. Biome Climatic Niche Model

i) Extent: Okanagan Nation Territory



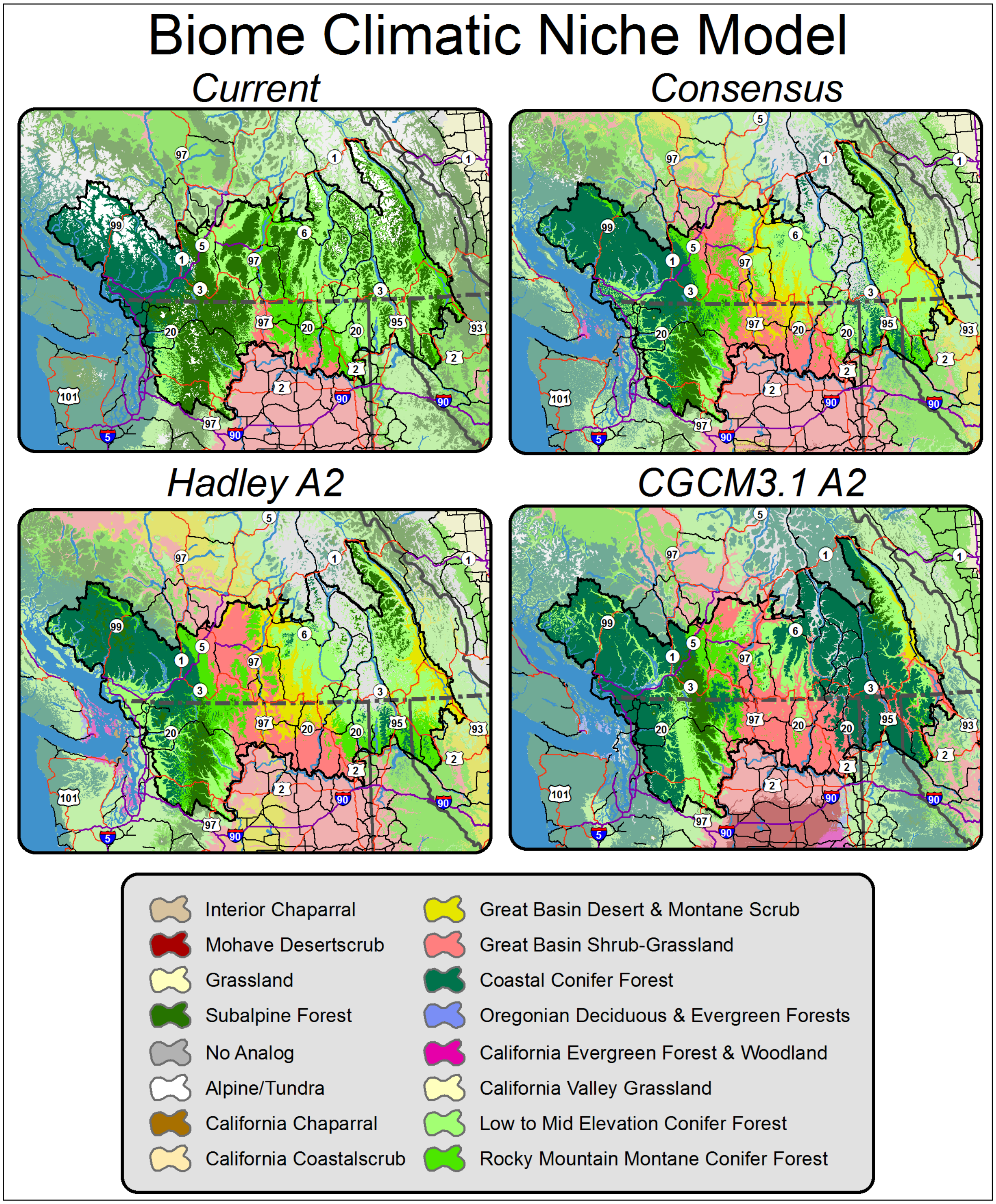
Appendix L.4a. Biome Climatic Niche Model

ii) Extent: Okanagan-Kettle Region



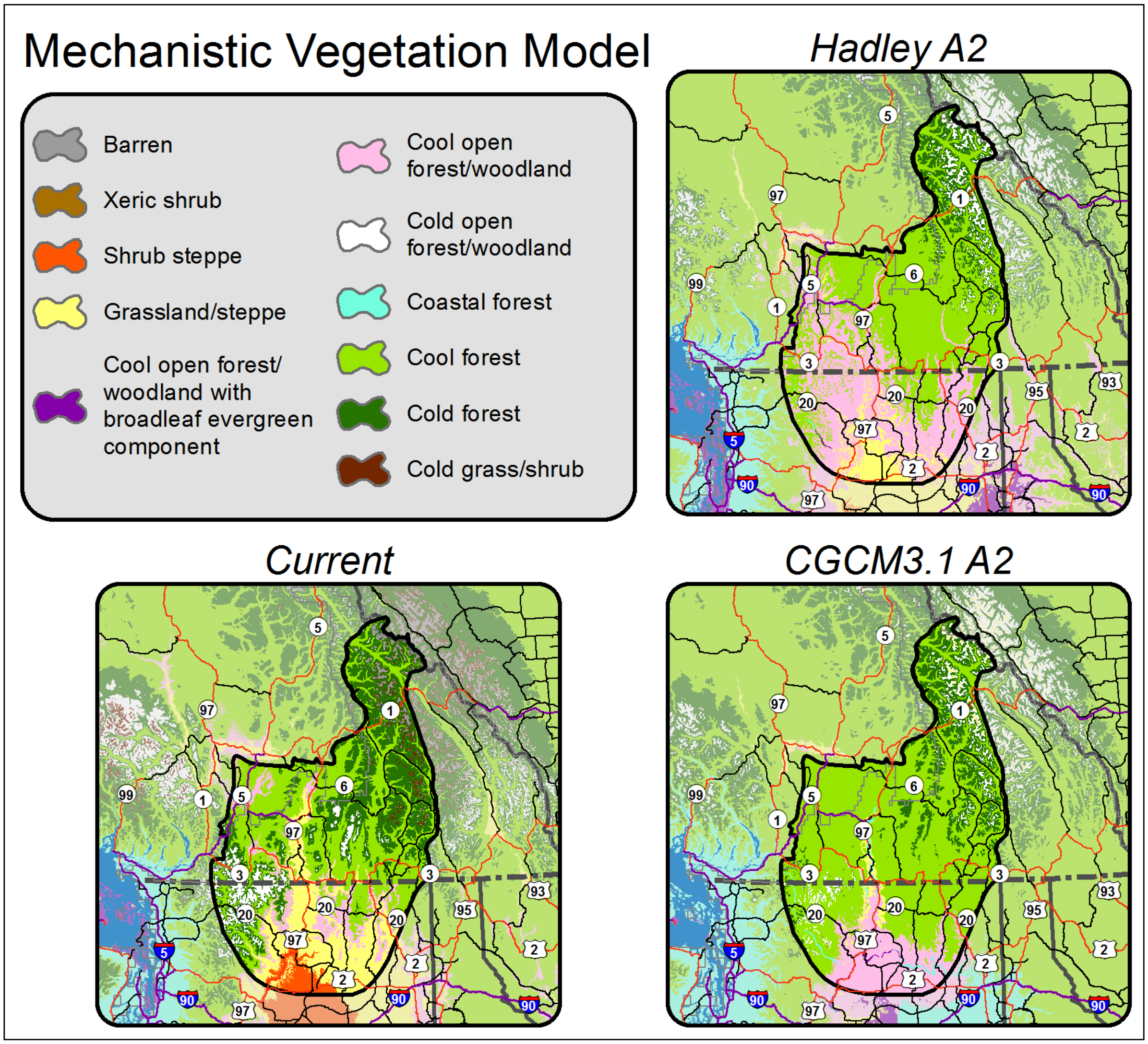
Appendix L.4a. Biome Climatic Niche Model

iii) Extent: Washington-British Columbia Transboundary Region



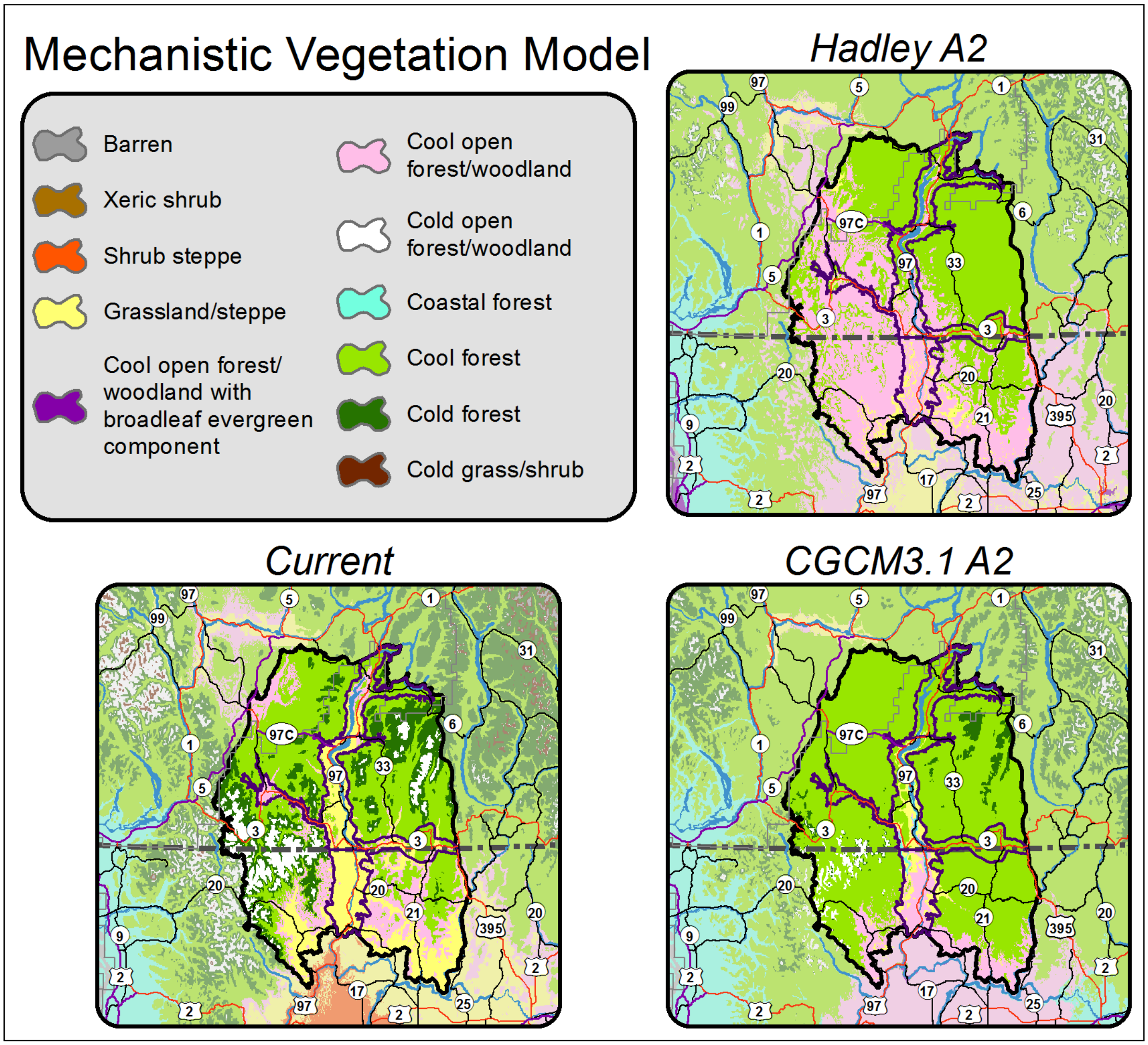
Appendix L.4b. Mechanistic Vegetation Model

i) Extent: Okanagan Nation Territory



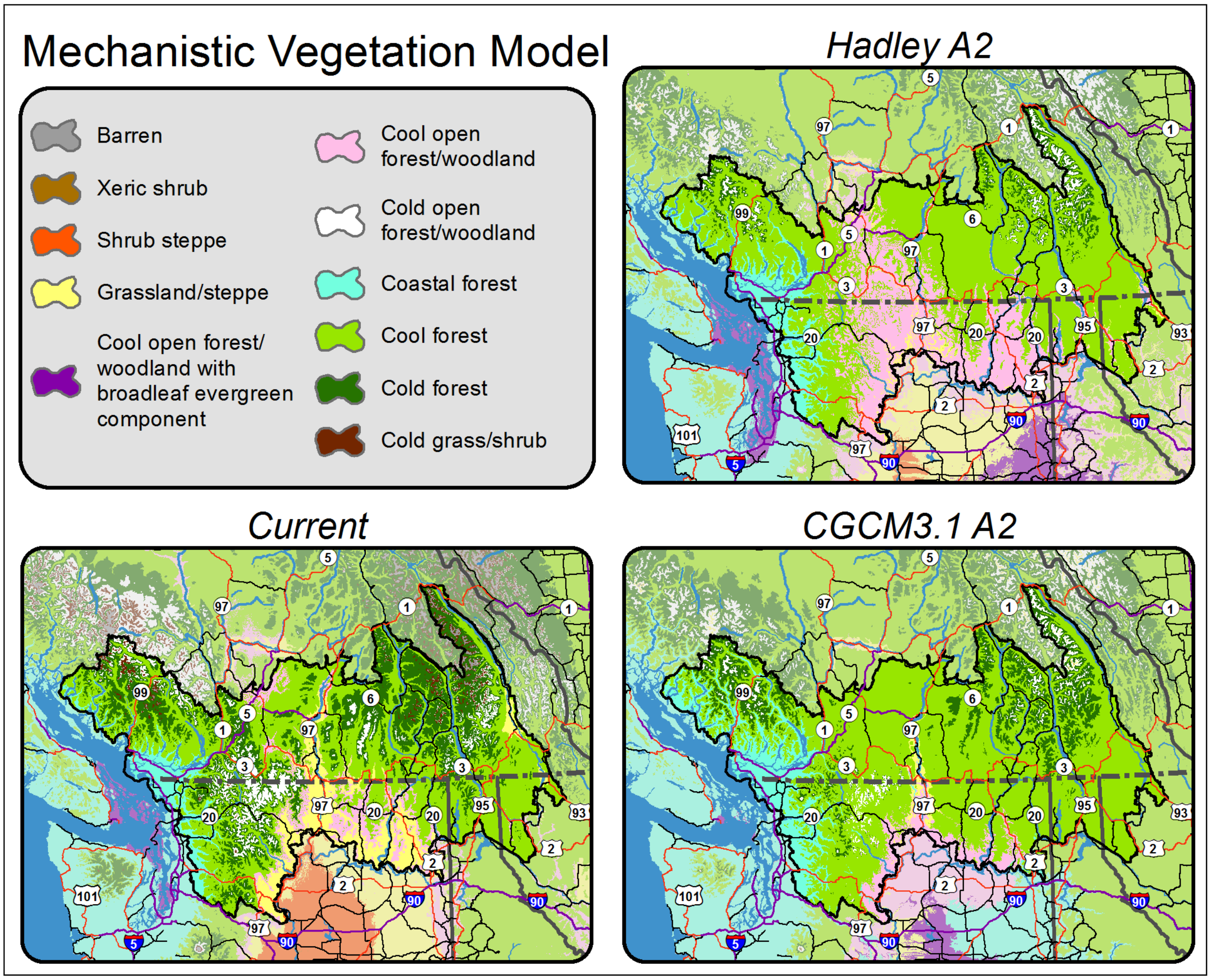
Appendix L.4b. Mechanistic Vegetation Model

ii) Extent: Okanagan-Kettle Region



Appendix L.4b. Mechanistic Vegetation Model

iii) Extent: Washington-British Columbia Transboundary Region



Appendix L.5. Projected Changes in Relevant Climate Variables

The following projections of future climate were identified by project partners as being most relevant to understanding and addressing climate impacts on shrub-steppe connectivity.[xviii] Future climate projections were gathered from two sources, except where otherwise noted: 1) the Integrated Scenarios of the Pacific Northwest Environment,[9] which is limited to the extent of the Columbia Basin; and the Pacific Climate Impacts Consortium's Regional Analysis Tool,[10] which spans the full transboundary region. For many climatic variables, noticeable differences in the magnitude of future changes can be seen at the US-Canada border; this artifact results from differences on either side of the border in the number of weather stations, the way temperature and precipitation were measured, and differences in the approach used to process these data to produce gridded estimates of daily weather variations.

a) **Days with High Fire Risk** (Energy Release Component, ERC > 95th percentile).[xix] This map shows the projected change in the number of days when the ERC – a commonly used metric to project the potential and risk of wildfire – is greater than the historical 95th percentile among all daily values.

b) **Spring (April 1st) Snowpack.** This map snows the percent change in snow water equivalent (SWE) on April 1st. April 1st is the approximate current timing of peak annual snowpack in Northwest mountains. SWE is a measure of the total amount of water contained in the snowpack. Projected decreases in SWE are depicted by the yellow to red shading.

c) **Total Spring Precipitation, March-May.** This map shows the projected change, in percent, in total spring (March-May) precipitation. Projected changes in total spring precipitation are depicted by the yellow to green shading.

d) **Soil Moisture, July-September.** This map shows the projected change, in percent, in summer soil moisture. Projected changes in soil moisture are depicted by the brown to green shading.

e) **Dry Spell Duration.** This map shows the projected change, in percent, in the maximum number of consecutive days with less than 1 mm of precipitation. Projected change in dry spell duration is depicted by the brown to green shading.

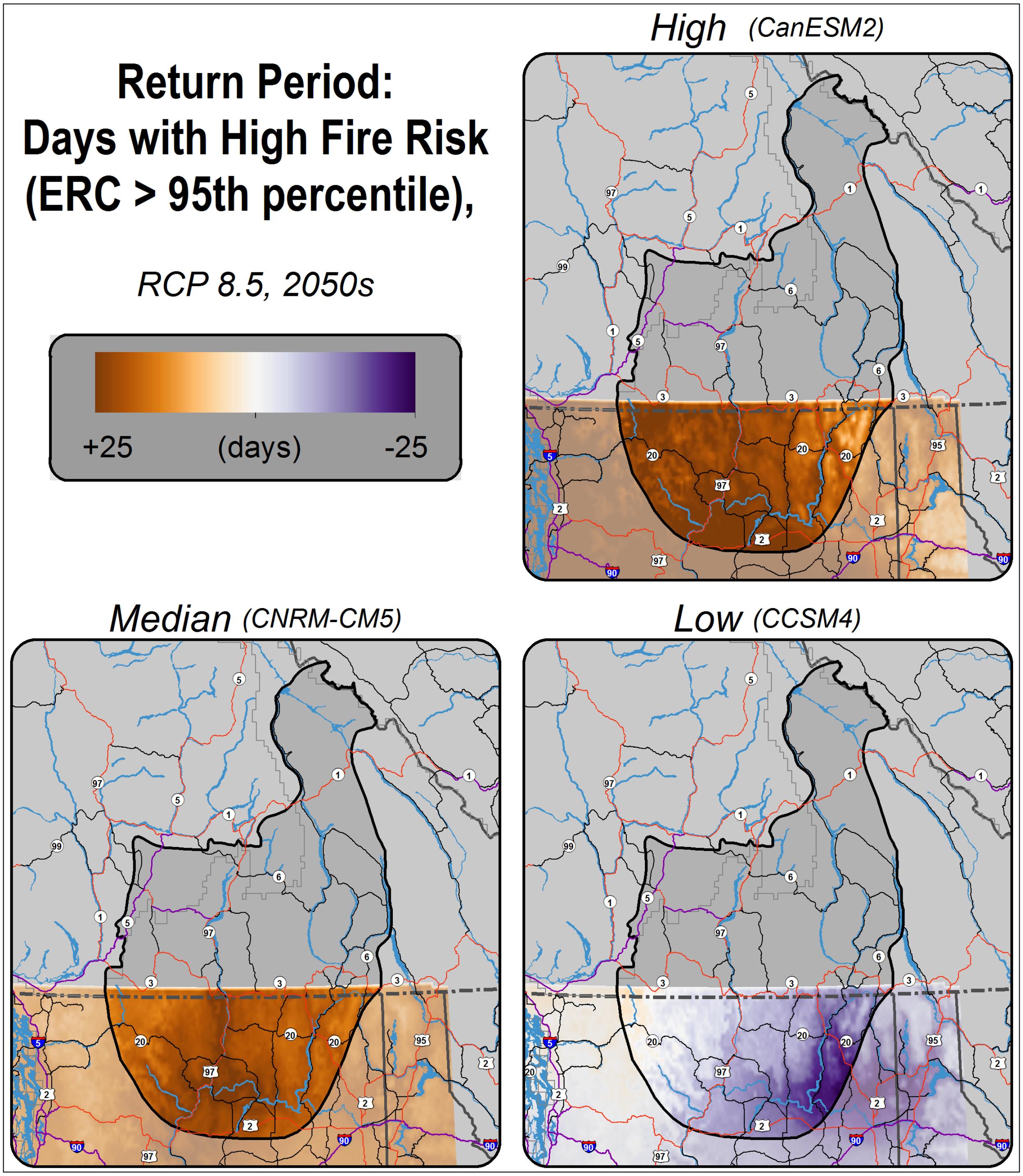
f) **Number of Frost Days.** This map shows the projected change, in percent, in the number of frost days, defined as the annual count of days when the daily minimum temperature is less than 0 degrees Celsius. Projected changes in the number of frost days are depicted by the yellow to red shading.

[xviii] All projections but "Days with High Fire Risk" are evaluated for the 2050s (2040-2069) and the 2080s (2070-2099), based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (CCSM4)), under a high greenhouse gas scenario (RCP 8.5). Days with High Fire Risk' is evaluated for the 2050s, based on 3 global climate models (a high (CanESM2), median (CNRM-CM5), and low (MIROC5)) using the RCP 8.5 (high) emissions scenario.

[xix] Abatzoglou, J.T. 2013. Development of gridded surface meteorological data for ecological applications and modeling. *International Journal of Climatology*, 33(1): 121-131.

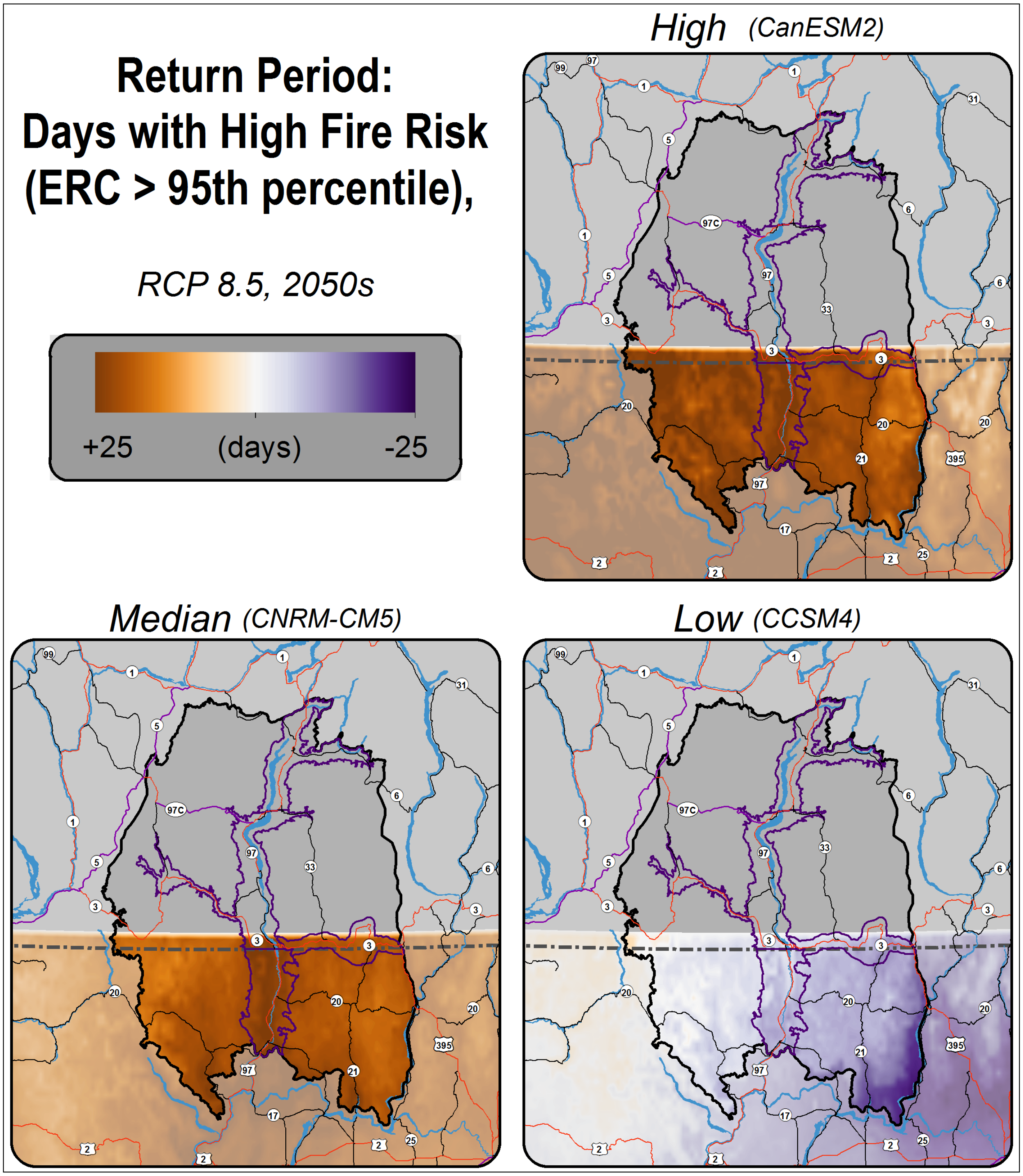
Appendix L.5a. Days with High Fire Risk

i) Extent: Okanagan Nation Territory



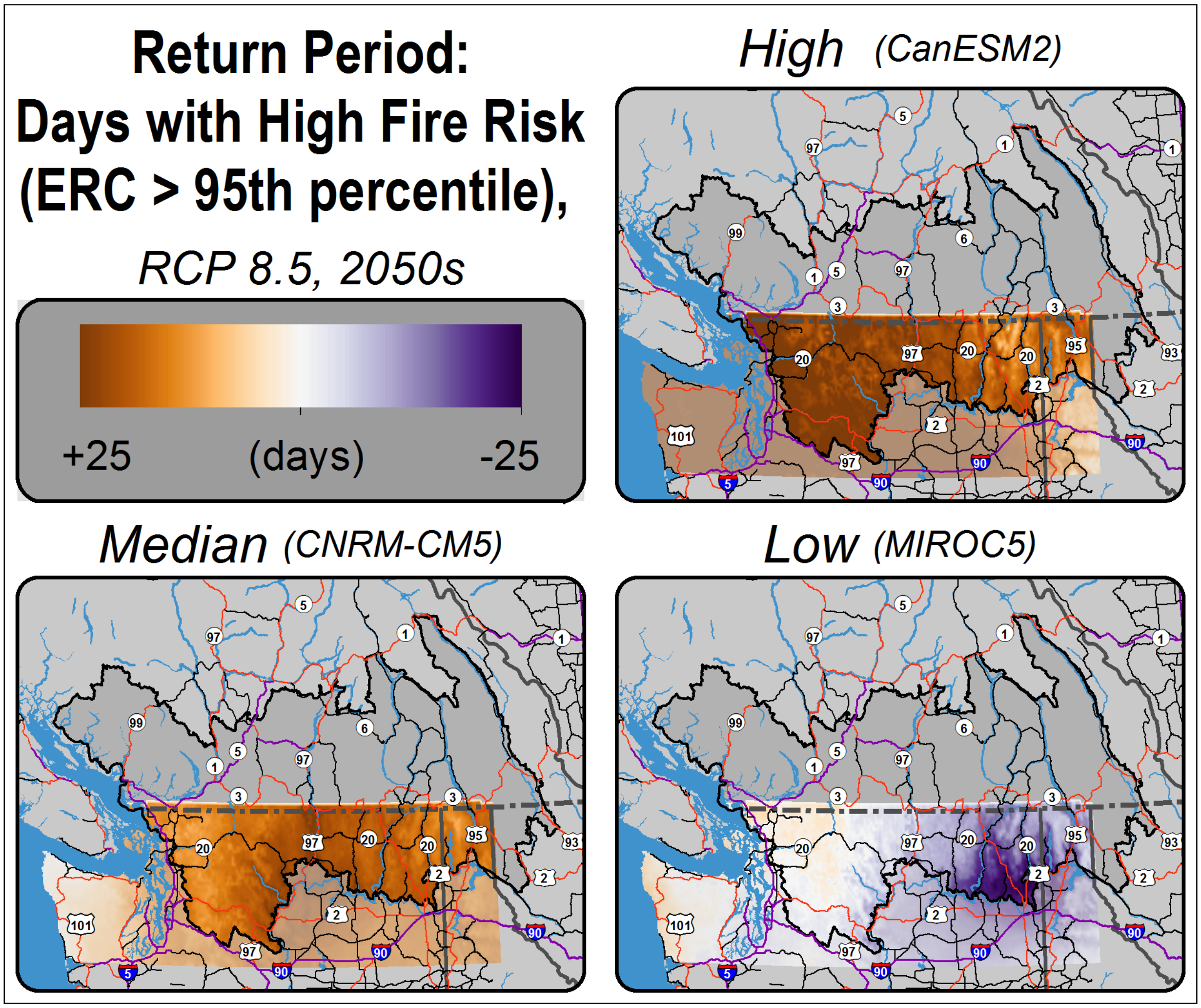
Appendix L.5a. Days with High Fire Risk

ii) Extent: Okanagan-Kettle Region



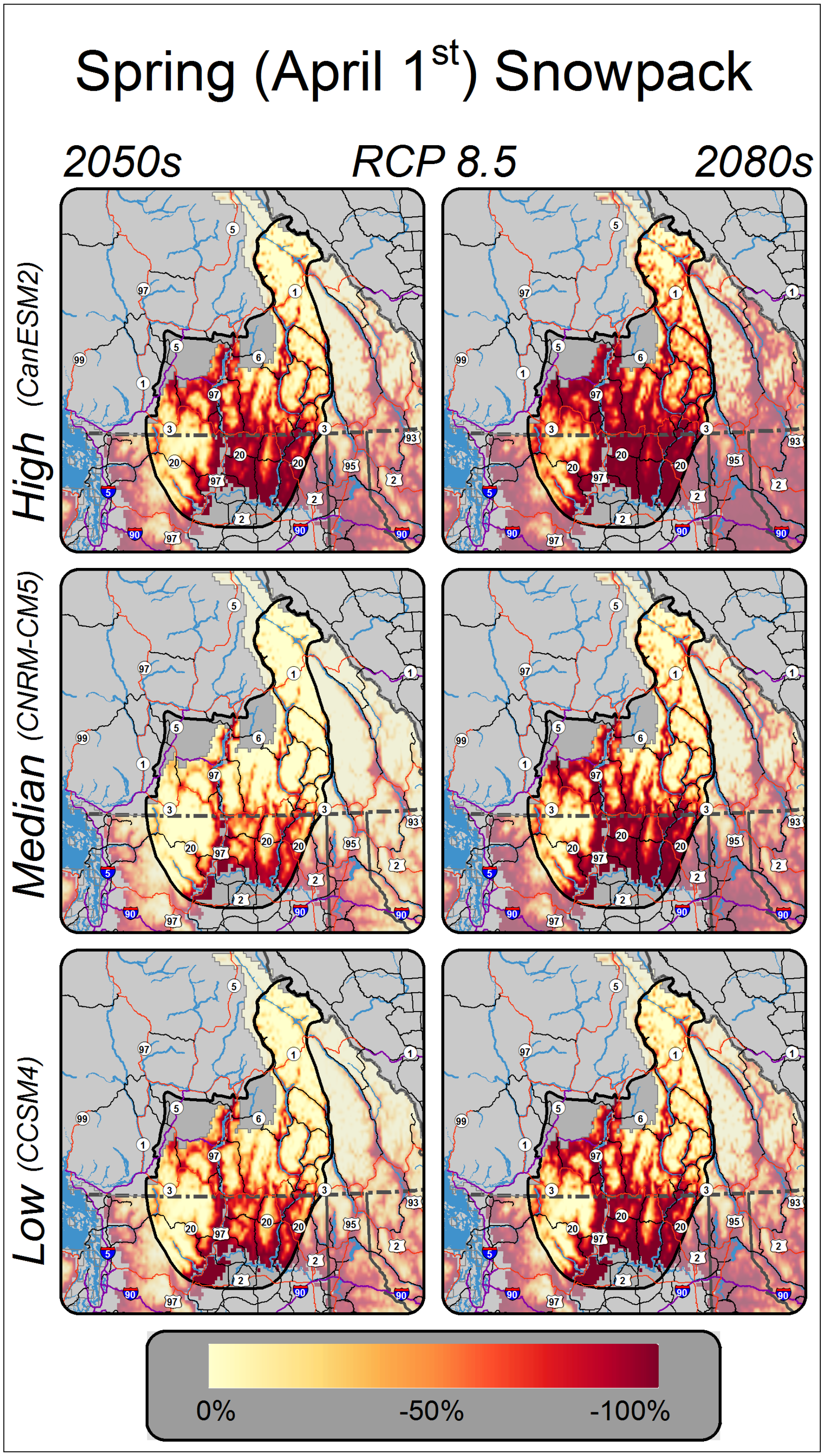
Appendix L.5a. Days with High Fire Risk

iii) Extent: Washington-British Columbia Transboundary Region



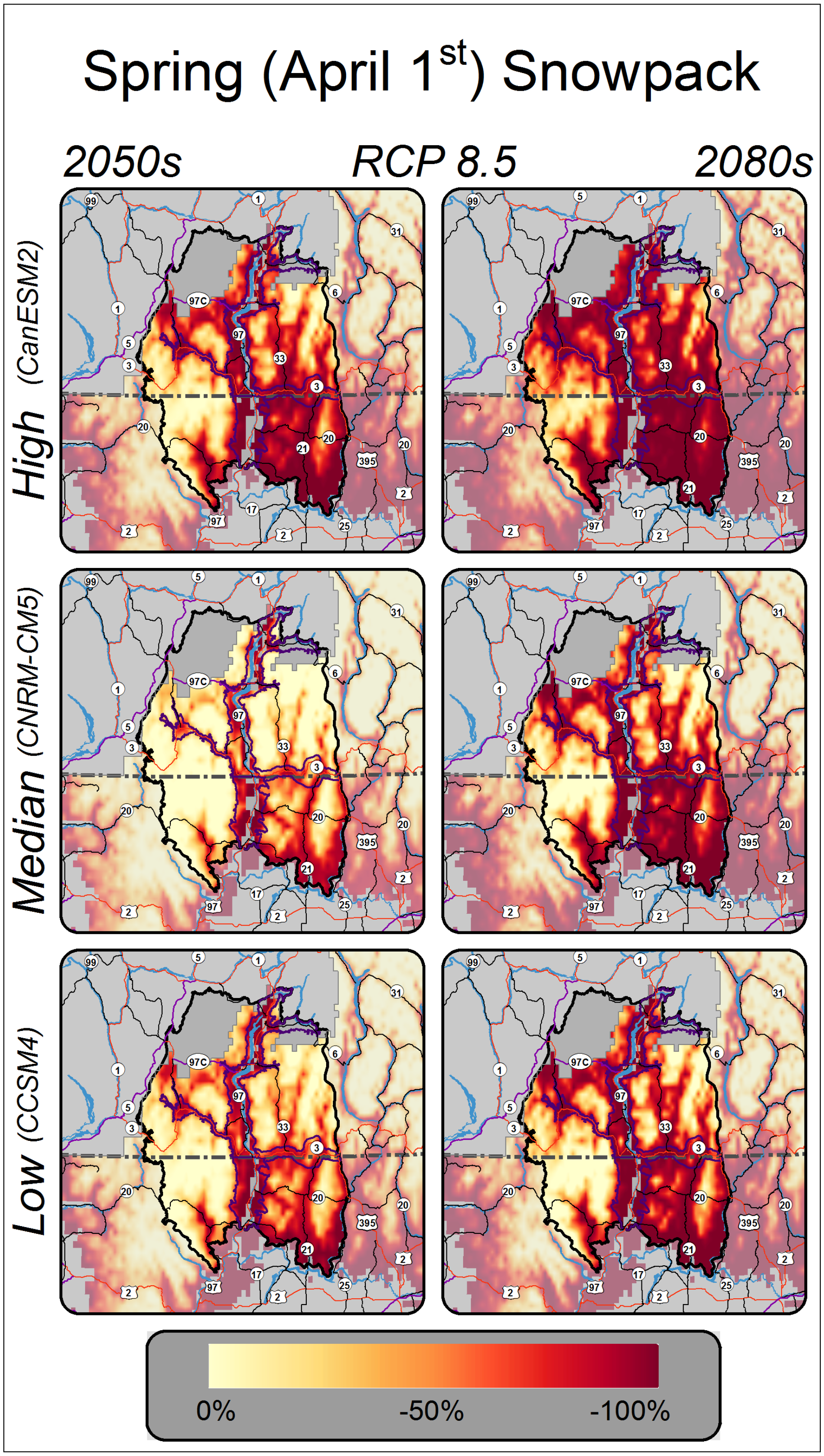
Appendix L.5b. Spring (April 1st) Snowpack

i) Extent: Okanagan Nation Territory



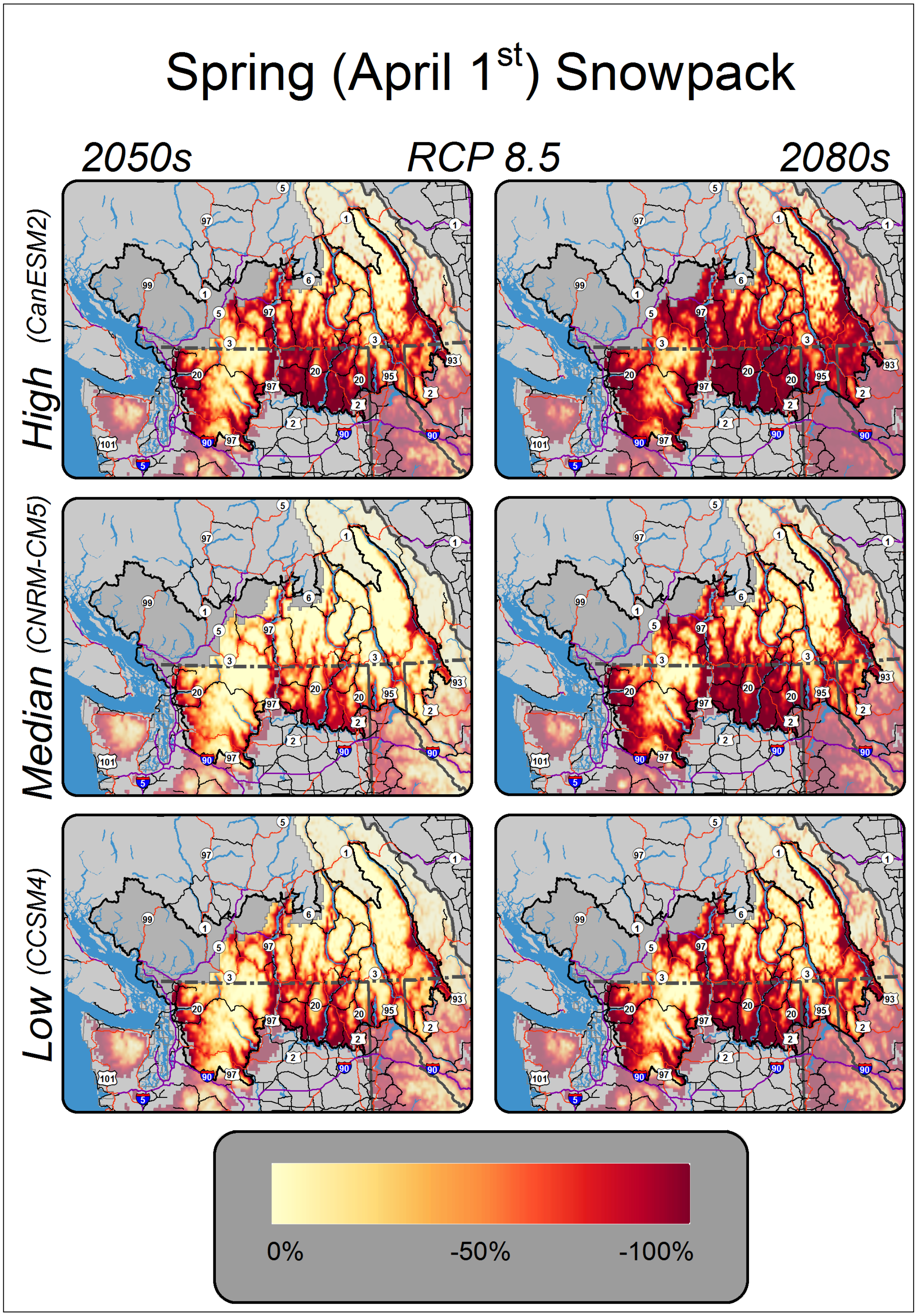
Appendix L.5b. Spring (April 1st) Snowpack

ii) Extent: Okanagan-Kettle Region



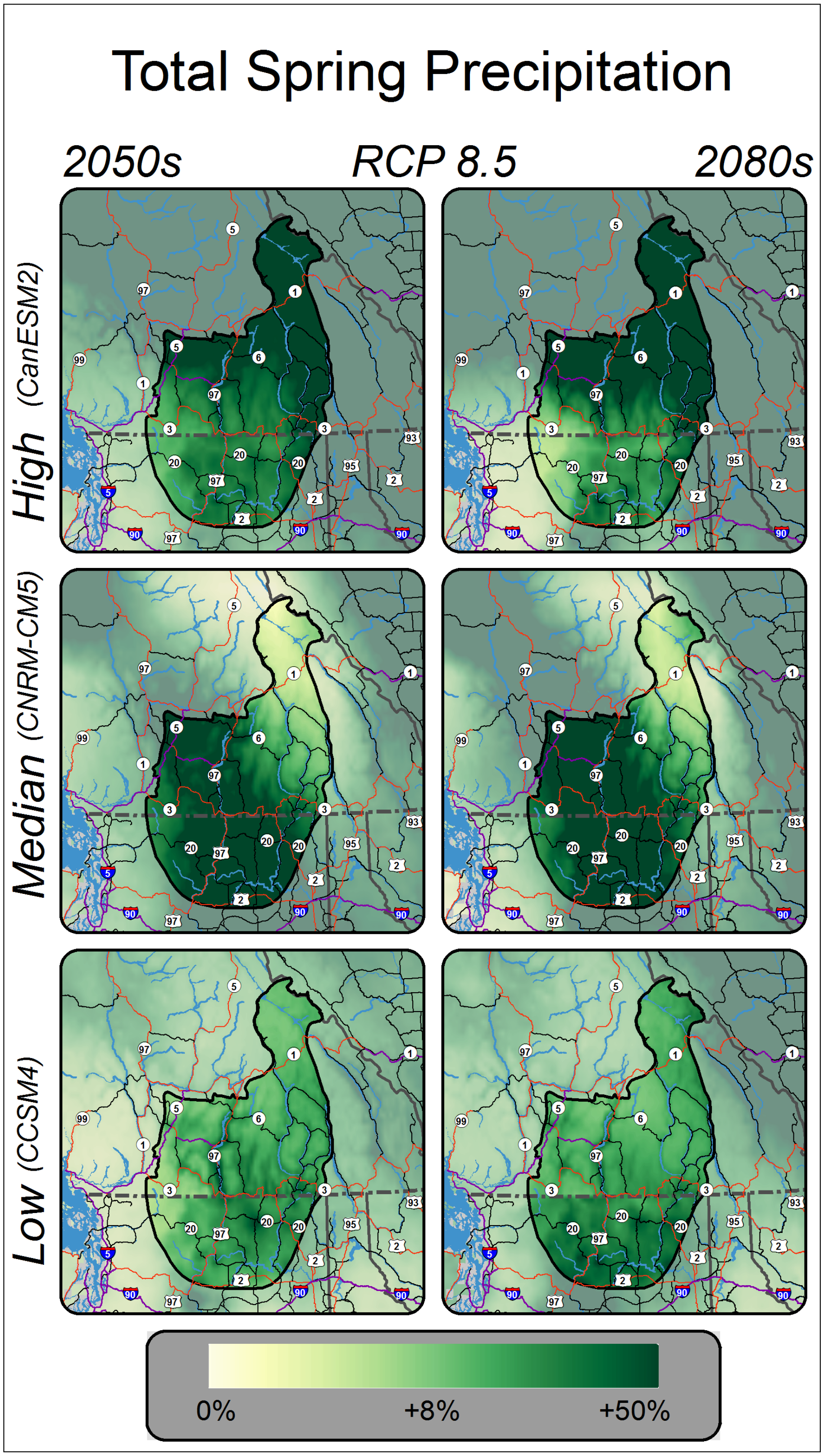
Appendix L.5b. Spring (April 1st) Snowpack

iii) Extent: Washington-British Columbia Transboundary Region



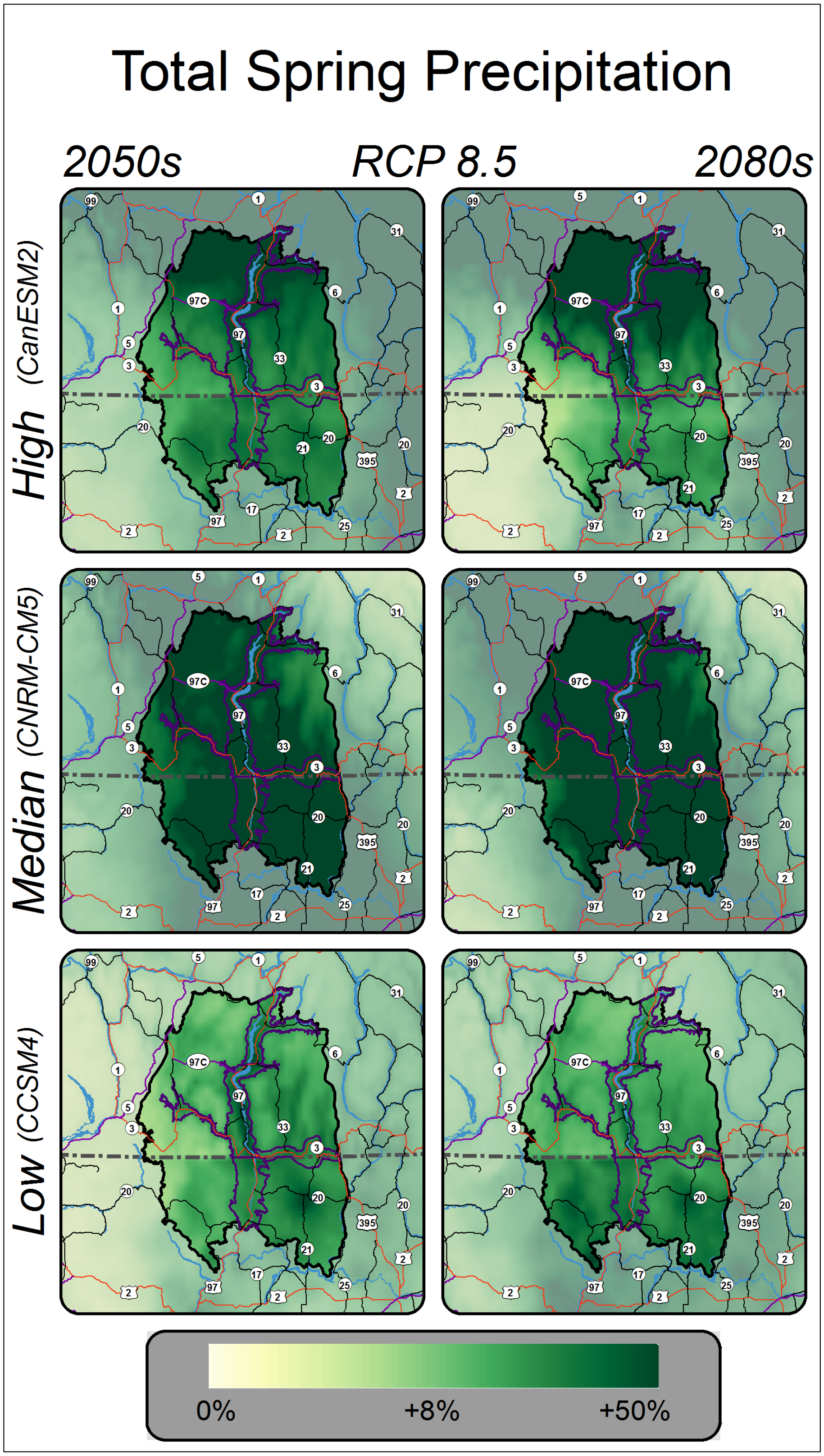
Appendix L.5c. Total Spring Precipitation, March-May

i) Extent: Okanagan Nation Territory



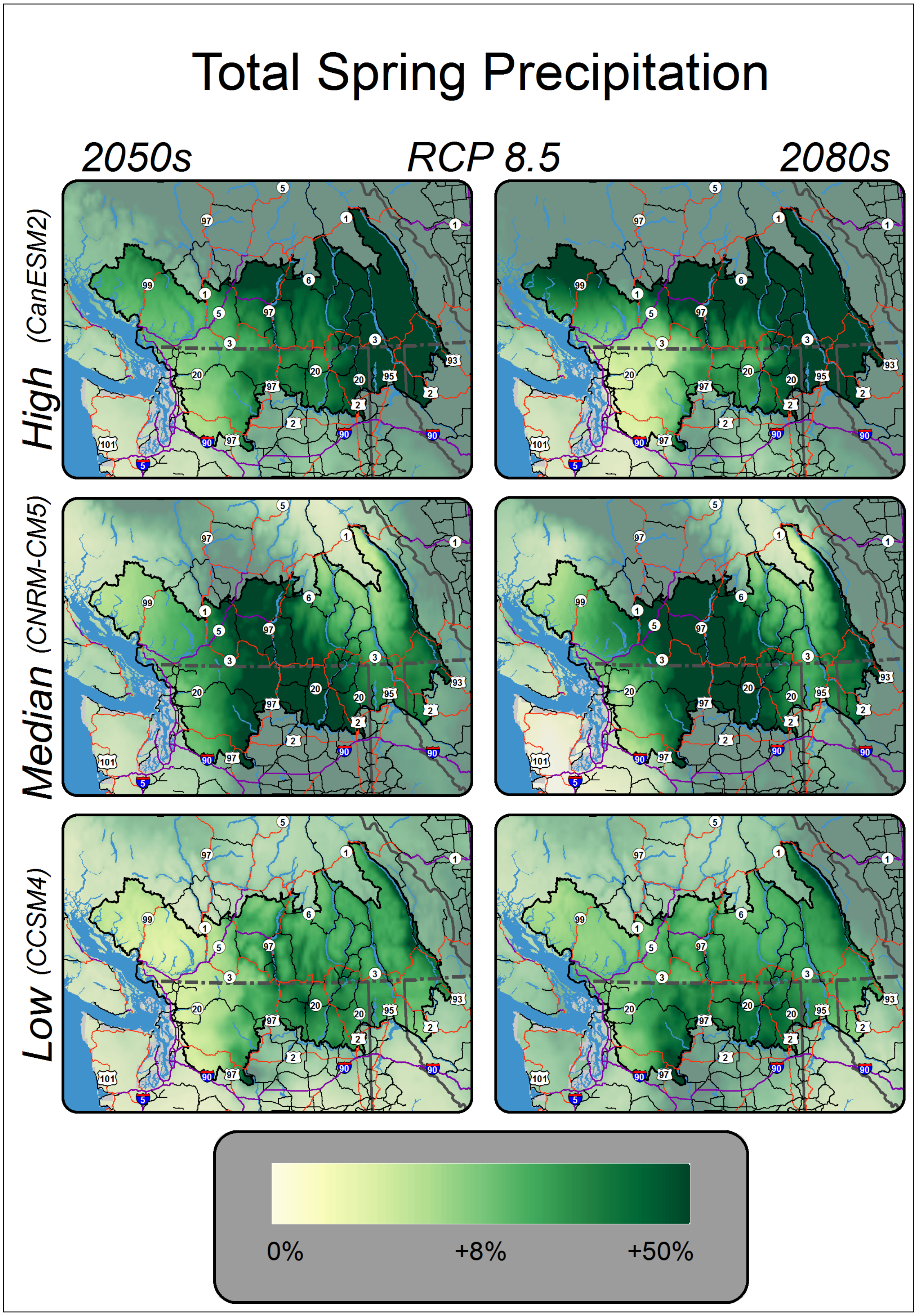
Appendix L.5c. Total Spring Precipitation, March-May

ii) Extent: Okanagan-Kettle Region



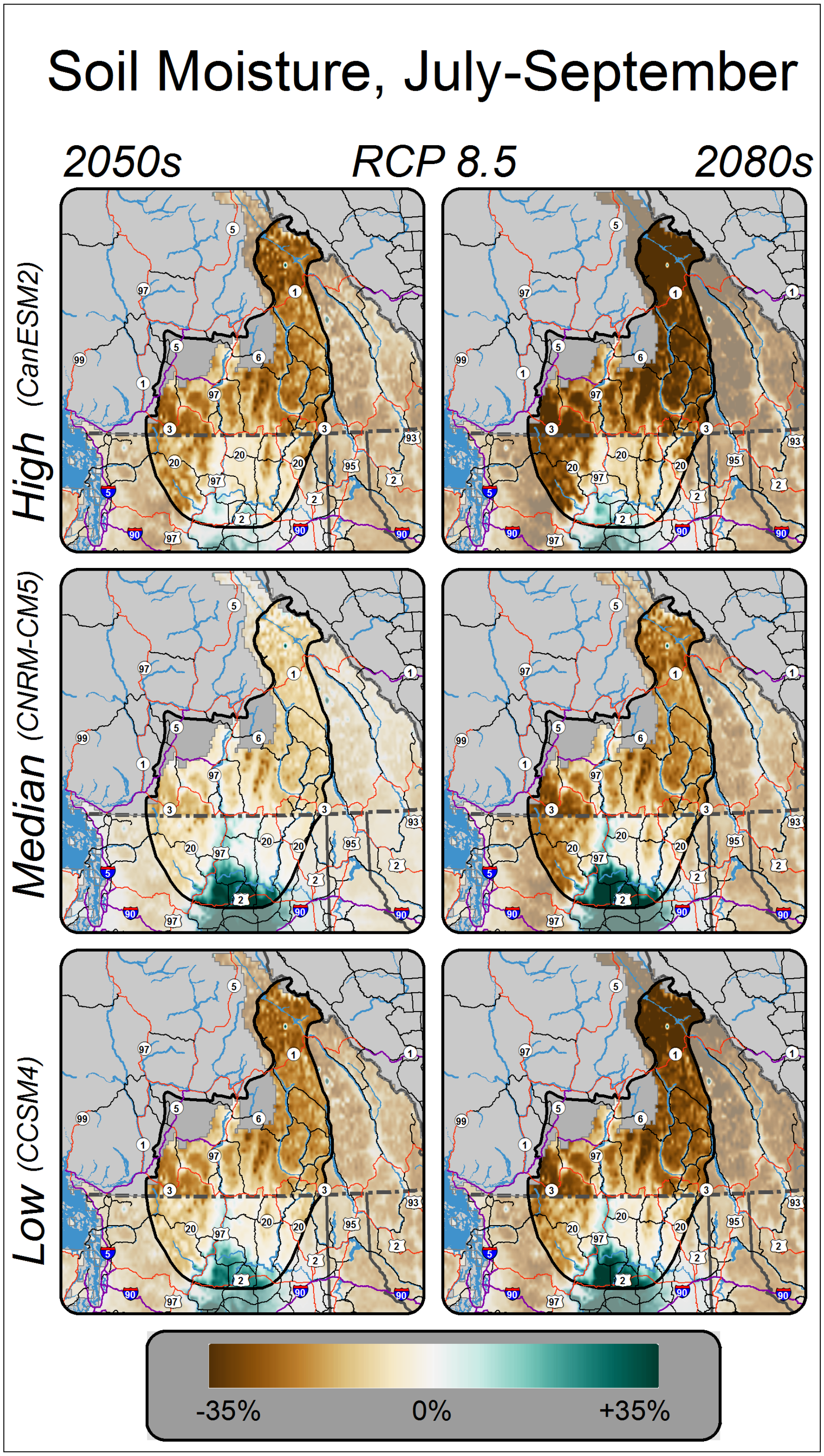
Appendix L.5c. Total Spring Precipitation, March-May

iii) Extent: Washington-British Columbia Transboundary Region



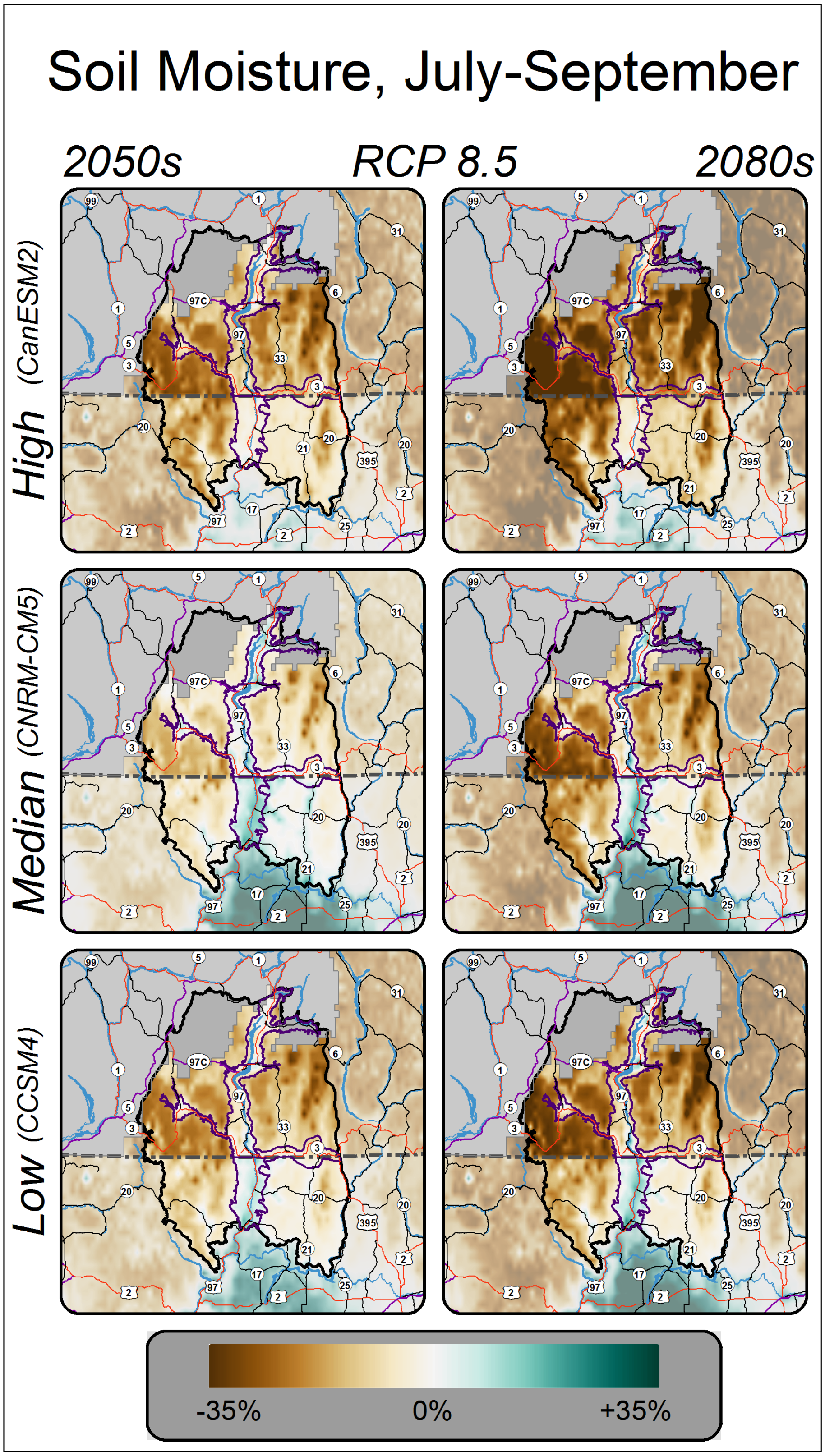
Appendix L.5d. Summer Soil Moisture, July-September

i) Extent: Okanagan Nation Territory



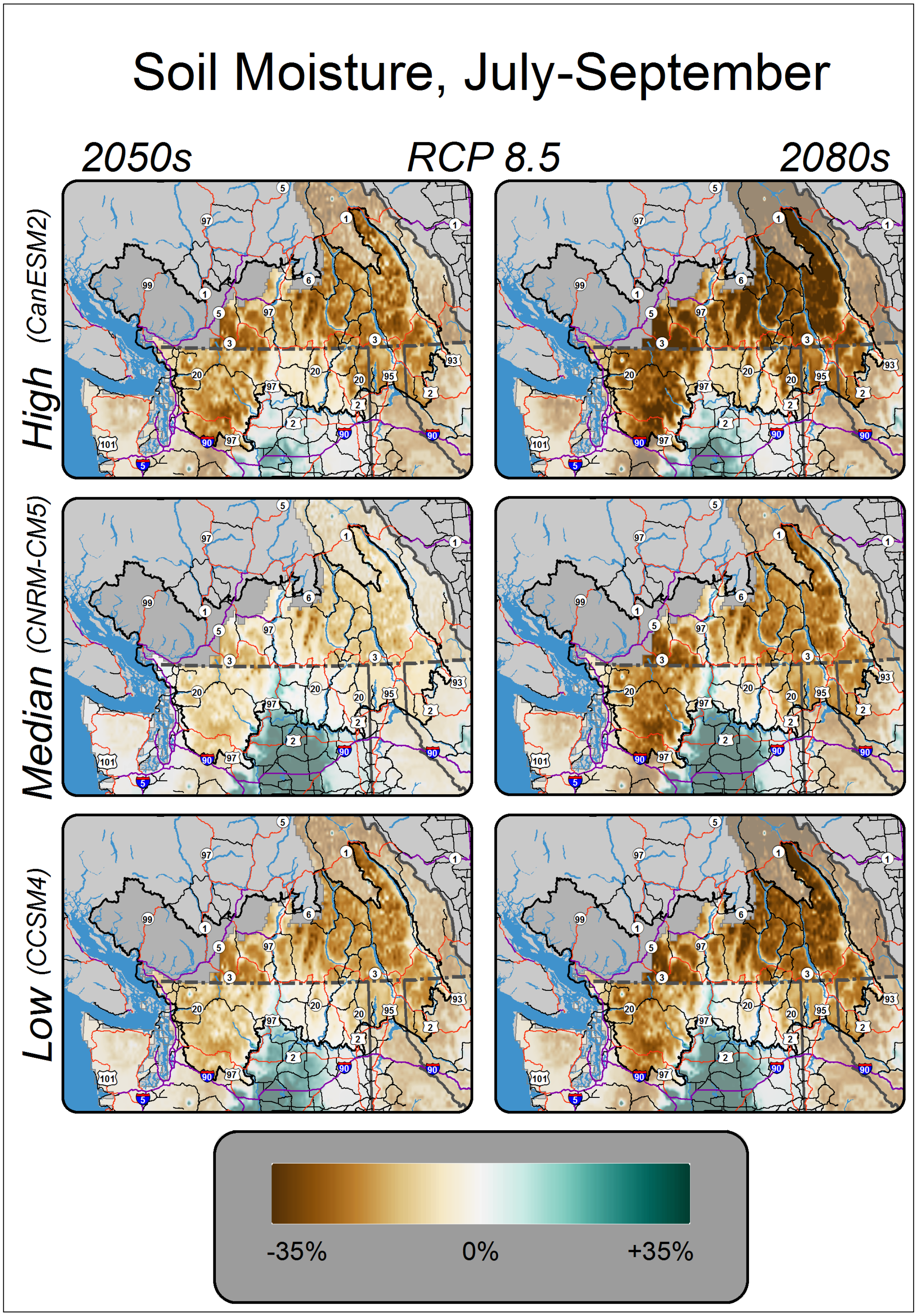
Appendix L.5d. Soil Moisture, July-September

ii) Extent: Okanagan-Kettle Region



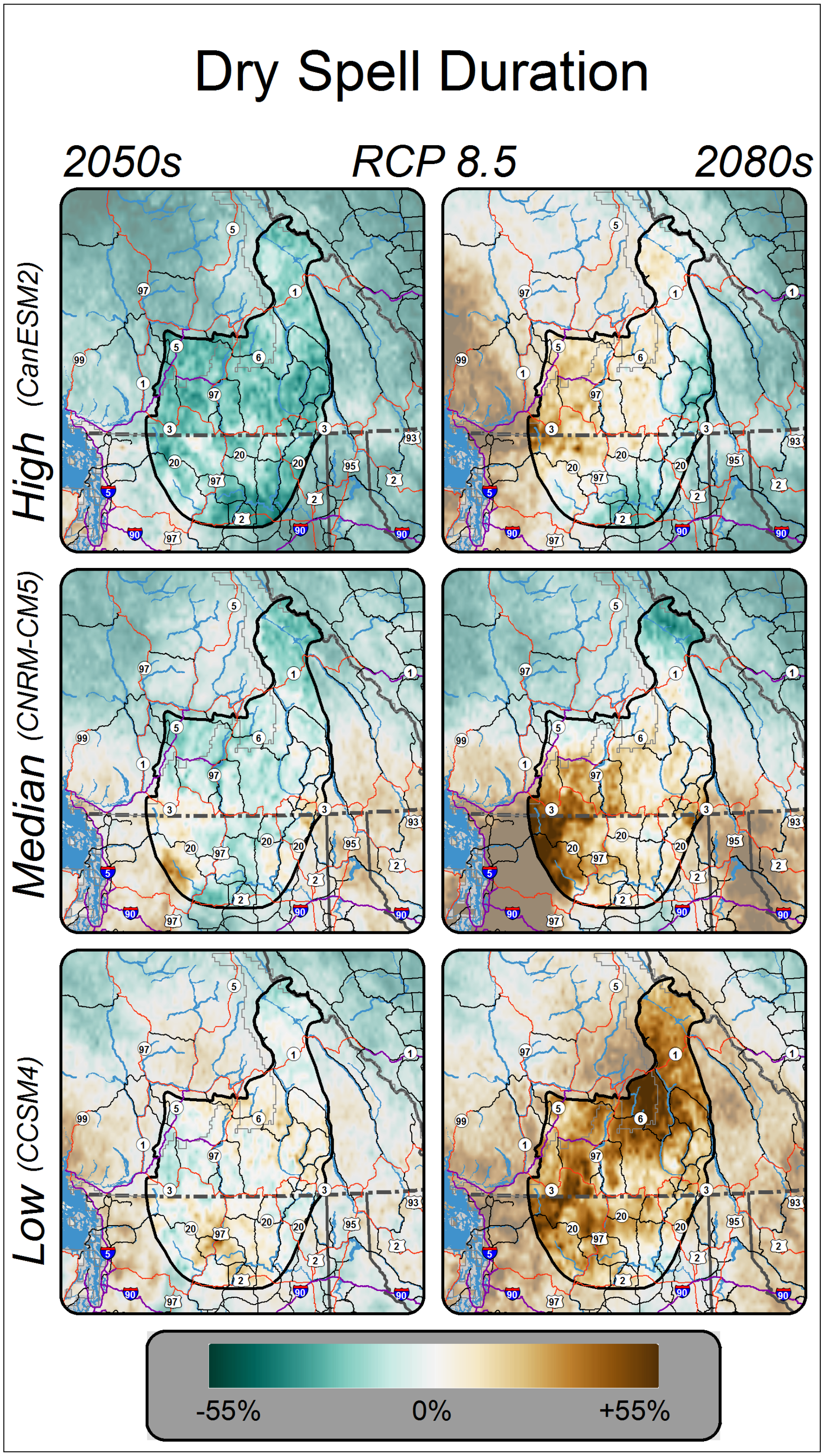
Appendix L.5d. Soil Moisture, July-September

iii) Extent: Washington-British Columbia Transboundary Region



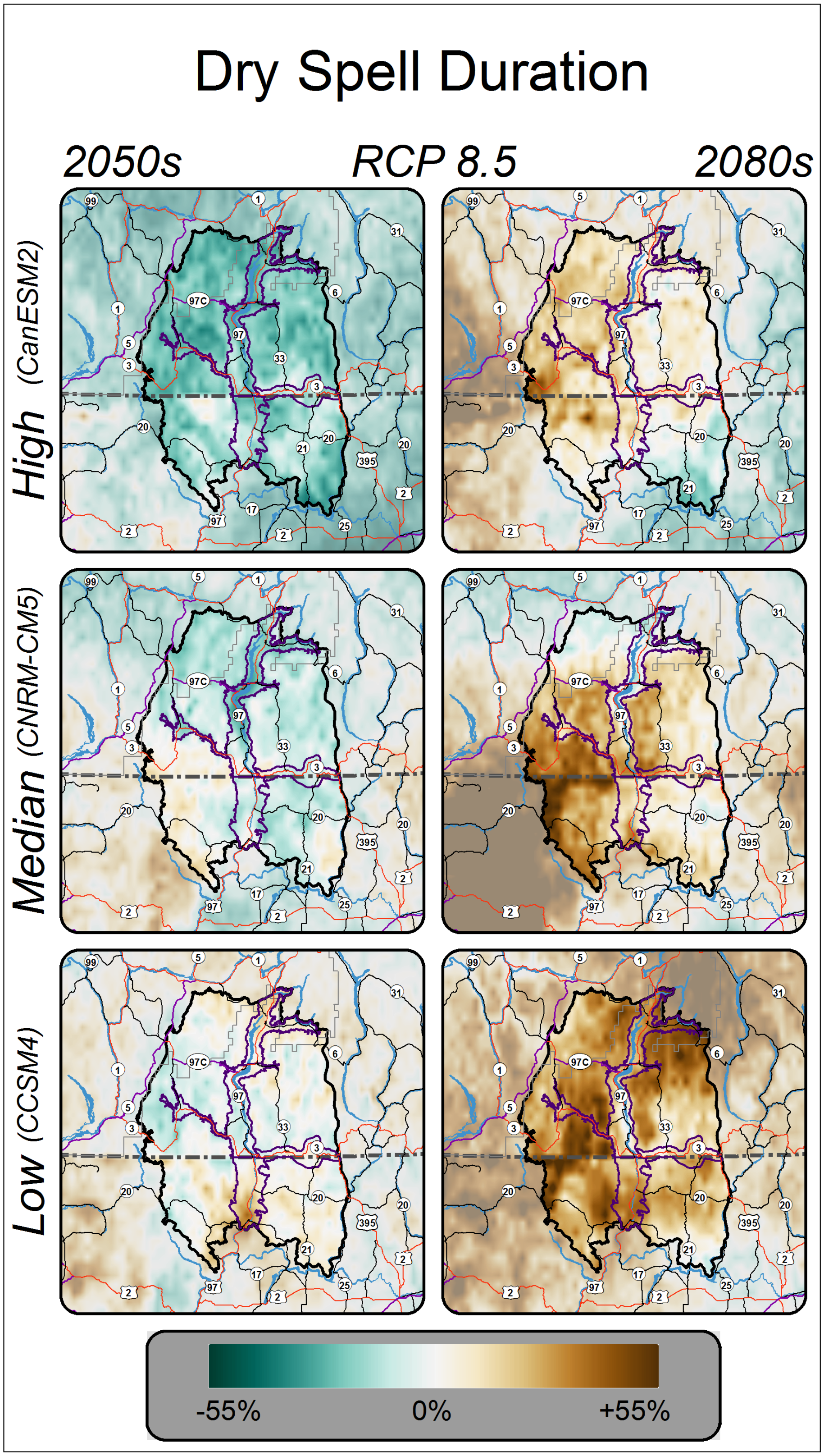
Appendix L.5e. Dry Spell Duration

i) Extent: Okanagan Nation Territory



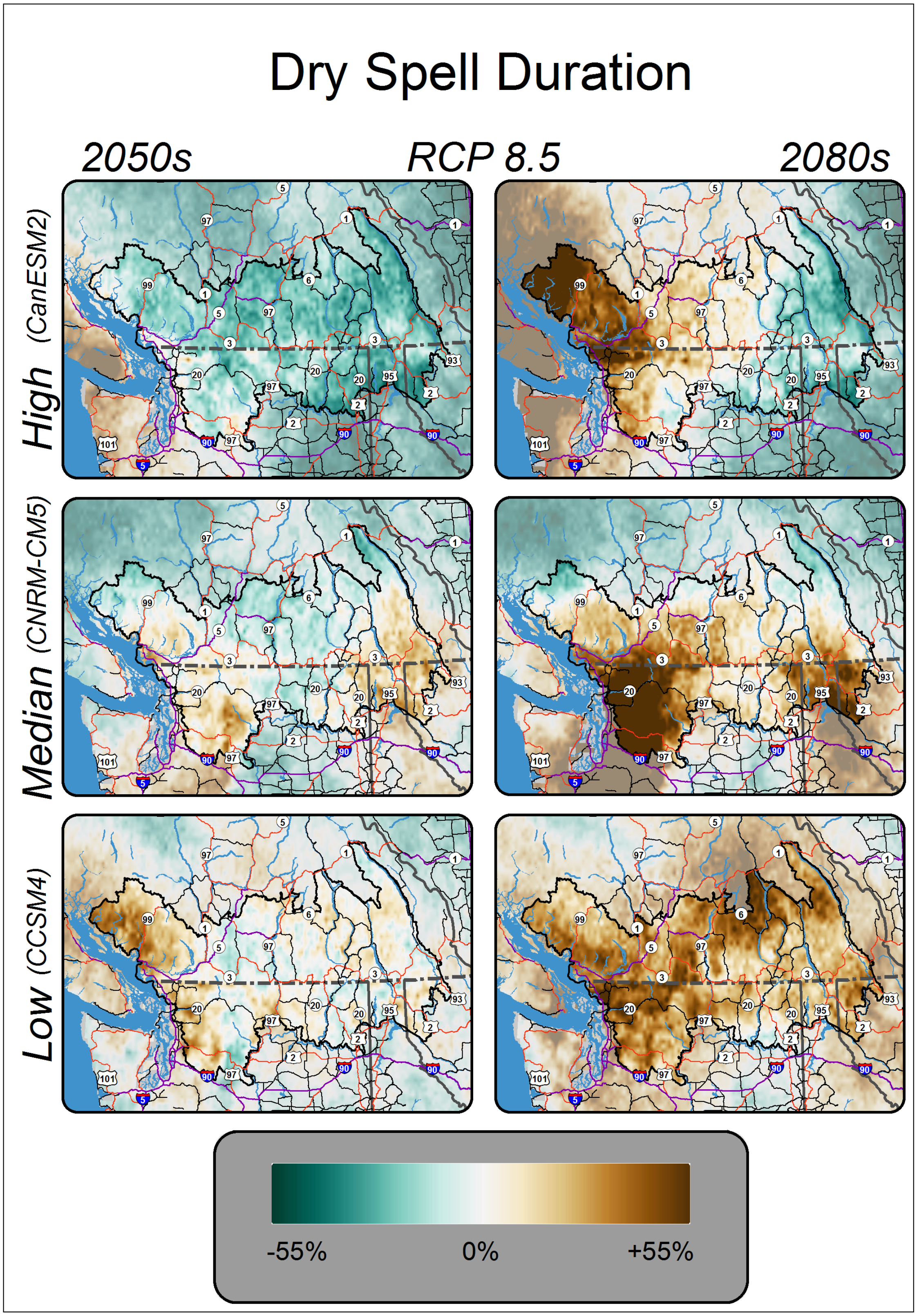
Appendix L.5e. Dry Spell Duration

ii) Extent: Okanagan-Kettle Region



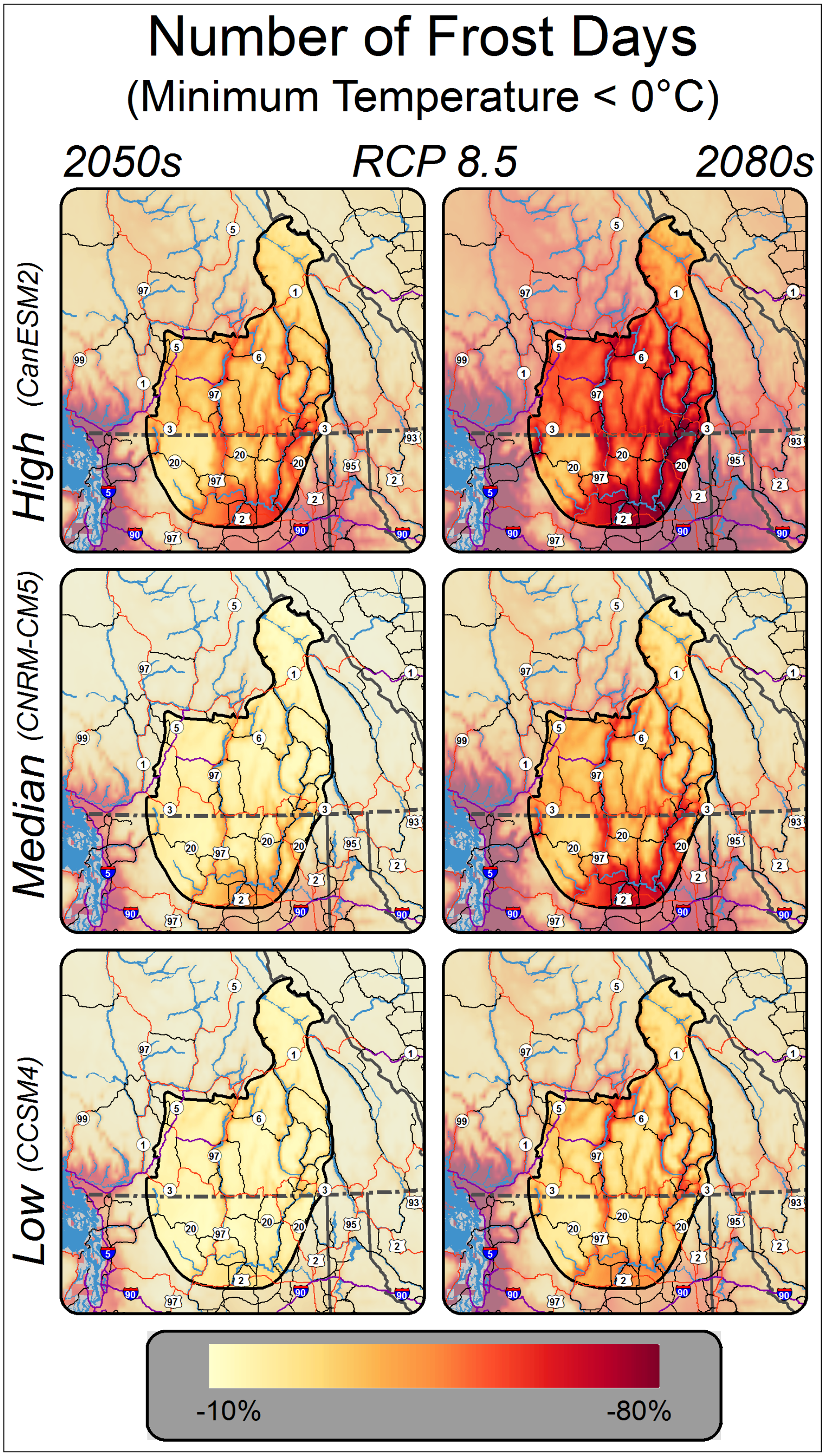
Appendix L.5e. Dry Spell Duration

iii) Extent: Washington-British Columbia Transboundary Region



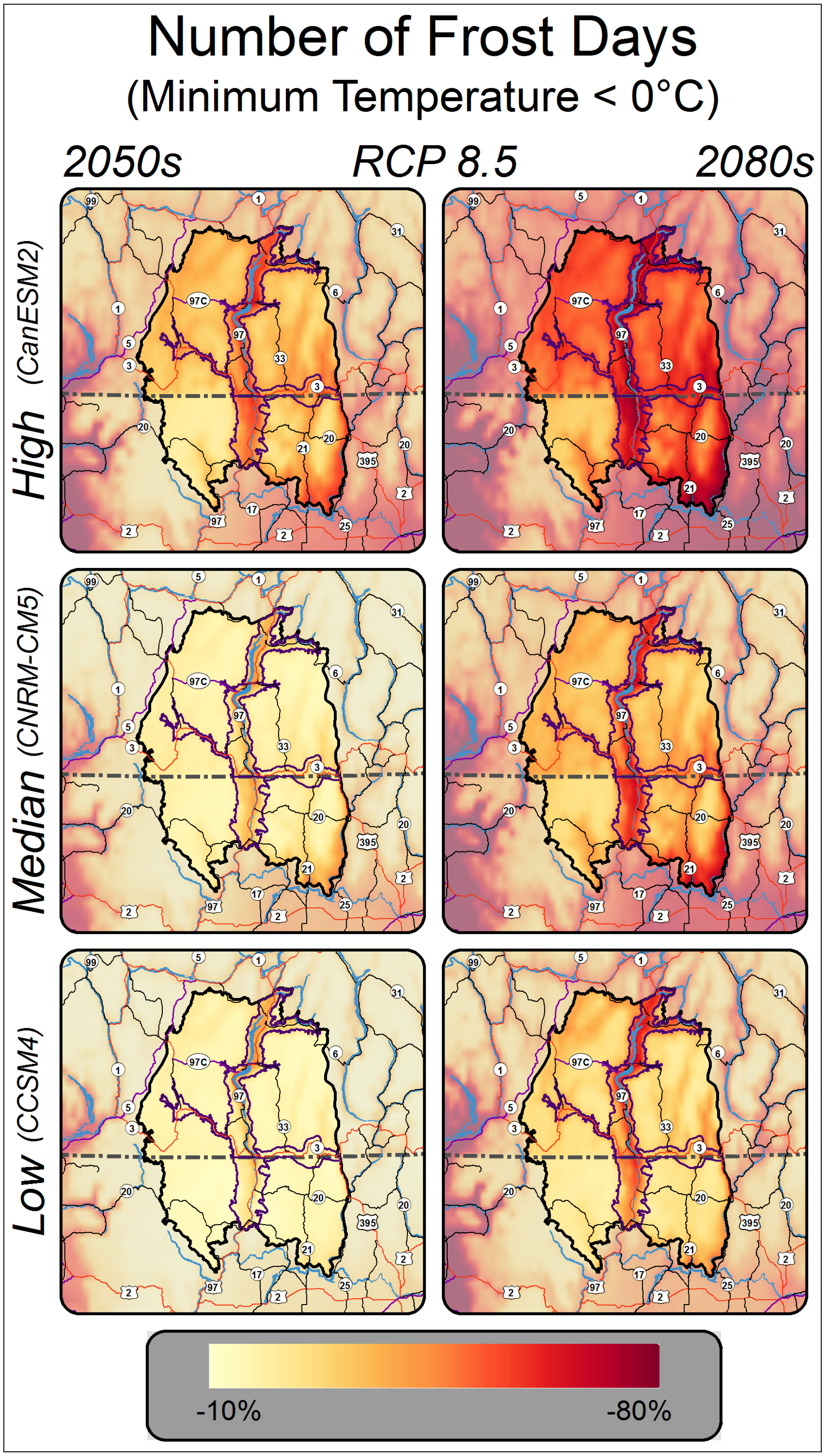
Appendix L.5f. Number of Frost Days

i) Extent: Okanagan Nation Territory



Appendix L.5f. Number of Frost Days

ii) Extent: Okanagan-Kettle Region



Appendix L.5f. Number of Frost Days

iii) Extent: Washington-British Columbia Transboundary Region